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Construction Dispute Mitigation: Quantitative and Qualitative Analytic Approach with a Focus on Bidding, Out-of-Sequence Work, and Contract Analysis

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I am submitting herewith a dissertation written by Ibrahim Salah Abotaleb entitled "Construction Dispute Mitigation: Quantitative and Qualitative Analytic Approach with a Focus on Bidding, Out-of-Sequence Work, and Contract Analysis." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

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Construction Dispute Mitigation:
Quantitative and Qualitative Analytic Approach with a Focus on Bidding, Out-of-Sequence Work, and Contract Analysis

A Dissertation Presented for the

Doctor of Philosophy

Degree

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Ibrahim Salah Eldin Abotaleb

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DEDICATION

I dedicate this work to my *parents*, my sister *Nadia*, and my fiancée and future wife *Dina*. Their love, patience, encouragement, and understanding always drive me forward and keep me going. I would also like to dedicate this work to my late brother, Mohamed. May your memory and love always be in my heart. Furthermore, I dedicate this work to my professors and mentors throughout my entire educational journey.

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ABSTRACT

The complexity of today's construction projects deems conflicts and disputes unavoidable. The mere presence of disputes leads to productivity losses, schedule overruns, cost overruns, and quality decline. Moreover, failure to resolve disputes in a quick manner ripples these impacts and prevents successful completion of projects. Accordingly, preventing disputes prior to taking place is always better than resolving them after the fact. There are several factors that cause disputes. However, this dissertation focuses on those related to bidding, out-of-sequence (OOS) work, and contract administration of owner's obligations, due to the significant knowledge gaps that were identified in their research streams.

The goal of this research is to cover the identified knowledge gaps by providing various effective quantitative and qualitative means of dispute mitigation at the different stages of the project's lifecycle. To this end, the research has four main objectives; each corresponding to one of the identified major knowledge gaps. The objectives are: (1) develop an advanced model for construction bid price estimation that is able to draw sound statistical inferences even in cases of data incompleteness and dynamic behaviors of competitors; (2) present contract administration guidelines for utilizing employer's obligations clauses under the most widely used national and international standard forms of design-build contracts; (3) identify the causes and early warning signs of OOS work and their characteristics, as well as the best practices to avoid and mitigate its impacts, and (4) develop an advanced systematic model for analyzing the dynamics of OOS.

The objectives were achieved through multiple analytical quantitative and qualitative methods; utilizing Bayesian statistics, decision theory, contractual examinations, surveys and meetings, statistical analysis, decision support systems, and system dynamics simulation. The research has various intellectual merits as it tackles important research areas that have not been explored before and improves areas which needed improvement. The research also has practical merits as it provides project stakeholders with models and tools that are used in multiple stages of the project cycle to mitigate disputes. The intellectual and practical outcomes of this research will partake in further understanding construction projects, minimizing disputes at different stages, and promoting healthier contracting environments.

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INTRODUCTION

1.1 Overview

The risks and complexities of construction projects, as well as the differing views of the involved participants, deem construction claims unavoidable (Abdul-Malak and Abdulahi 2017). Claims are used by the contractors to recover additional unlawful incurred costs during construction, and by owners to recover the additional costs caused by the poor execution of the contractor (El-adaway and Kandil 2010). The number of claims made in construction projects has significantly increased both in size and number in the last 30 years (Harmon 2003). The evidence of this increase in the U.S. and Canada is very compelling, and includes the following facts: (1) half of claims made requested a 30% or more increases original contract prices; (2) a third of claims requested 60% or more increases in original contract prices; and (3) some claim requested amounts very close to the entire original contract price (Cheeks 2003). It is estimated that construction claims in the U.S. cost around $5 billion per year, and there are no indicators stipulating that such costs are going to decrease with the current practices (Peña-Mora et al. 2002).

Claims are the initial representation of conflicts; where conflicts exist when there is incompatibility of interest (Chen et al 2014). When conflicts are not settled using the means outlined in the contract, they turn into disputes; which are settled using either litigation in courts or the more practical dispute resolution mechanisms (ADR) such as arbitration, dispute review boards, mediation, and mini trials (El-adaway and Ezeldin 2007). However, no matter how disputes are handled, their mere presence in itself has adverse impacts on cost, schedule, and quality (Abotaleb and El-adaway 2017). Globally, the average value of disputes has increased from $35.1 million to in 2010 to $46 million in 2016 (Arcadis 2016). Also, the average length for handling disputes has increased from 9.1 months in 2010 to 15.5 months in 2015 (Arcadis 2016). The increase in the volume of claims and disputes causes contractors' major detriment. For example, in one case a major contractor was able to recover 91% of its claimed amounts after a 3-year arbitration process, causing them significant financial loss (El-adaway and Kandil 2009).

There is a consensus among practitioners and researchers that disputes are one of the main factors which prevent the successful completion of construction projects (Abotaleb and El-adaway 2017, Perera 2016, Cakmak and Cakmak 2014). Most standard construction contracts will stipulate a dispute resolution mechanism that if used will ensure the fulfilment of contractual duties and to provide remedies to the breach of those duties (Spurin 2003). However, even the least disruptive of these dispute resolution methods still negatively impact construction projects (El-adaway and Ezeldin 2007). As such, preventing disputes from the beginning is always better than resolving them (Chang and Ive 2003, Arcadis 2016). To this end, this research aims at providing various effective means of construction dispute prevention and mitigation at the project pre-award and post-award stages throughout quantitative and qualitative approaches.

Considerable research efforts have been undertaken to identify and categorize the causes of disputes in the construction industry. With all such efforts, the categorization made by Cheung and Pang (2013) remains one of the finest as it provides various levels of classification and includes different sorts of logical relationships among them. Cheung and Pang (2013) distinguish two types of construction disputes: contractual and speculative, as shown in Figure 1.1.

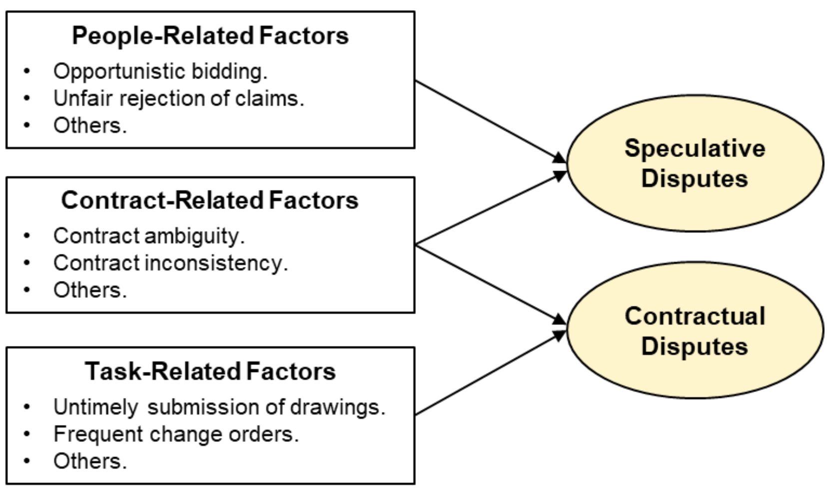


Figure 1.1. Anatomy of Construction Disputes (Abstracted from Cheung and Pang 2013).

The contractual disputes are fueled by task-related factors while the speculative ones are fueled by people-related factors. In addition, both contractual and speculative disputes are caused by contract-related factors. People-related factors are those initiated by behavioral/affective conflicts and opportunistic strategies between the parties such as opportunistic bidding by contractors in tenders and sinuous rejection of contractors' claims by owners (Ho and Liu 2004). Task-related factors result from the divergent views on rights and responsibilities arising from the tasks with examples including untimely submission of drawings by consultants and frequent change orders by owners (Jergeas 2011). Finally, contract-related factors are those which purely associate to the contract agreement such as contract ambiguity, inconsistency, or incompleteness (Cheung and Pang 2013).

1.2 Problem Statement

Factors that trigger disputes can take place at any project stage. For example, in the *bidding stage*, contractors submitting low bids have higher chances of being awarded projects. However, when they are awarded, they become claim-oriented to recover losses resulting from their unrealistic bids. This claim-driven behavior results in disputes that lead to severe quality, schedule, and cost impacts (Nash and Wolanski 2010). In the *negotiations* stage, when the contract terms are not properly drafted or well-understood, the project will encounter disputes with almost full certainty (Jaffar et al. 2011). In fact, research has shown that poor administration of contracts is the most common cause of disputes (Arcadis 2016). In the *construction* stage, disruptions and changes take place almost in all projects, leading to out-of-sequence work, which in turn leads to further disruption, loss of productivity, overruns in cost, decline in quality, etc. Mishandling such disruptions and out-of-sequence work is a major cause of "loss of productivity" claims and disputes; at which contractors demand extension of time and increase in contract sum to make up for the lost productivity. Moreover, from a managerial point of view, sometimes policies that seem logical (such as using overtime to compensate for lost productivity) lead to rippled impacts (such as turnover and decline in morale) and result in opposite outcomes that are unforeseen using traditional analytical techniques. Preventing disputes resulting from these types of policies require more advanced analytical techniques that consider multiple feedbacks. Such advanced techniques would enable better decision-making; thus, partaking in preventing disputes in the construction stage. Even if disputes occur in the construction stages and are left till the project *closeout* stage, such techniques would provide substantial help in resolving them in a timely manner.

Of course, there are several other sources of disputes; however, the focus of this dissertation is on bidding, out-of-sequence work, and contract administration due to the significant knowledge gaps that were found in their research streams. The knowledge gaps that are tackled are as follows:

1. **Knowledge Gap A**: *There is a lack of models helping contractors determine optimal bid prices that maximize their probability of winning as well as expected profit; especially in cases of incomplete information or dynamic bidding behavior of their competitors (i.e. having bidding schemes that change significantly with time).*

2. **Knowledge Gap B**: *No works have been found that help parties in understanding the owner's contractual obligations, the associated required procedures, and the interrelated repercussions for failure to such provisions in design-build construction contracts.*

3. **Knowledge Gap C:** *Despite the fact that out-of-sequence (OOS) work is one of the top factors that lead to productivity loss, the root causes of OOS work and their impacts have not been investigated in the literature. Moreover, no best practices have been established for OOS avoidance and mitigation.*

4. **Knowledge Gap D**: *Traditional scheduling and modeling techniques fail to grasp the full impacts of OOS work due to their limited ability to capture the highly dynamic nature of multiple feedback processes and interdependencies between project elements. Such dynamics of OOS work are poorly, if not at all, studied in the literature.*

1.3 Research Goal, Objectives, Methodologies, and Direct Outcomes

The *goal* of this research is to cover the previously mentioned knowledge gaps by providing various effective quantitative and qualitative means of construction dispute prevention and mitigation at the different project stages. It shall be noted that the word "prevention" does not mean elimination; since it is almost impossible to eliminate disputes. The word "prevention" in the context of this research refers to "minimization". In other words, the aim of the research is to "minimize" the disputes that could arise during the project by "preventing" the actions and policies that lead to such disputes.

The research has 4 objectives, one corresponding to each of the gaps. The *objectives* are:

1. Develop an advanced model for construction bid price estimation that is able to draw sound statistical inferences even in cases of data incompleteness and dynamic behaviors of competitors;
2. Present contract administration guidelines for utilizing owner's obligations clauses under the most widely used national and international standard forms of design-build contracts;
3. Identify the causes and early warning signs of OOS work and their characteristics, as well as the best practices to avoid and mitigate its impacts, and
4. Develop an advanced systematic model for analyzing the dynamics of OOS work.

1.4 Research Plan

Each of the 4 research objectives is tackled in a separate chapter in this dissertation. Figure 1.2 shows each objective and its associated methodology that is followed as well as the outcomes. The upper part of Figure 1.3 shows the organization of this dissertation. The lower part of Figure 1.3 shows the project lifecycle and how each of the dissertation chapters applies to them. The first chapter is an introductory one; discussing the problem statement, presenting the knowledge gaps that need to be addressed, and defining the goal and objectives of this research.

The second chapter presents a decision-theoretic model for enhanced construction bidding using decision theory and Bayesian statistics; thus, covering the first objective. The model is developed to ensure proper profits for contractors as well as high probability of winning construction bids; thus, minimizing the claims and disputes resulting from unbalanced bids.

The third chapter investigates OOS work as a major trigger for "loss of productivity" claims. In this chapter, OOS work is studied in depth in terms of causes, early warning signs, impacts, and best preventive and reactive practices for avoiding and mitigating OOS work; thus, covering the second objective. The chapter concludes by presenting a decision support tool for helping the project stakeholders in avoiding OOS work and mitigating its impacts at different project stages.

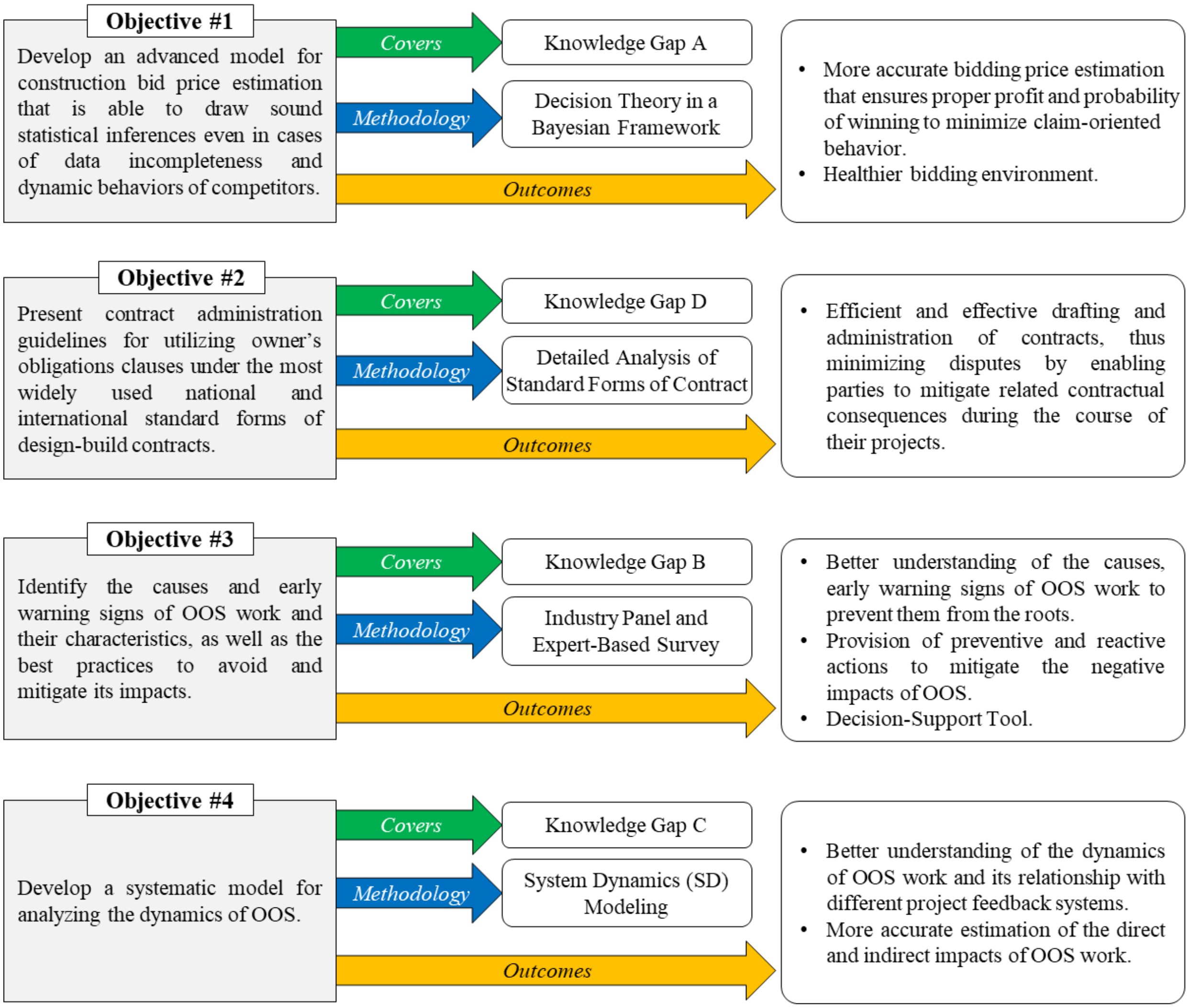


Figure 1.2. Research Objectives, Methodologies, and Outcomes.

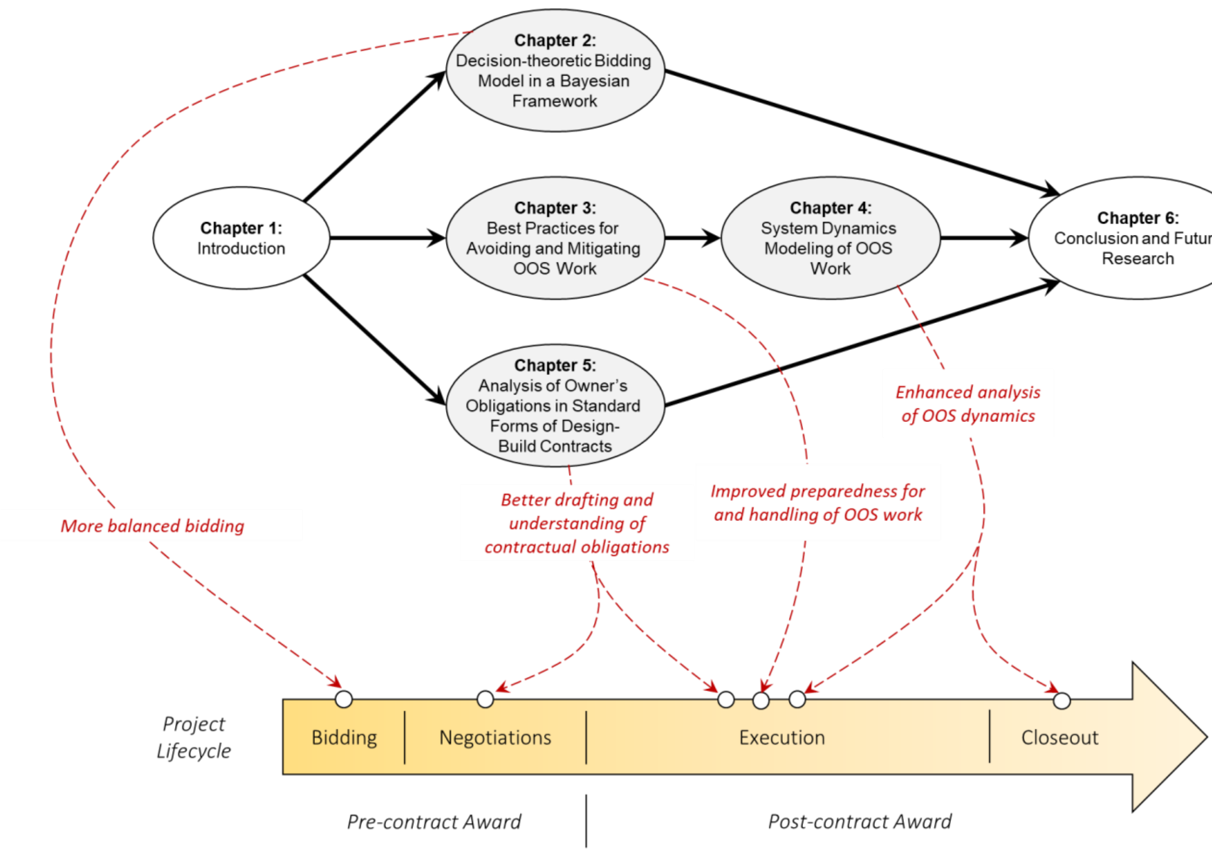


Figure 1.3. Research Direction and Benefits.

The fourth chapter presents an advanced system dynamics model for analyzing OOS work and enhancing the management process of construction projects. When an OOS event comes about, several impacts take place. Owners usually underestimate these impacts because they do not consider the indirect effects, and contractors overestimate them because they overemphasize the indirect effects. This misalignment caused by the blind spots of the traditional analysis techniques leads to disputes. The developed model in this chapter takes the project's complexity and interconnectivity into consideration to accurately calculate the direct and indirect impacts; thus, making it easier to resolve relevant claims before turning into disputes.

The fifth chapter analyzes national and international standard forms of contract and presents guidelines for drafting and administrating owner's obligations clauses. When the contract agreement clearly states the employer's obligations and both parties have clear understanding of the conditions, no party will mistakenly undertake an unlawful right or obligation; thus, preventing various types of disputes from taking place - assuming good faith.

The sixth chapter includes conclusions and recommendations for future research directions. Chapters two to five are referred to as the "*technical chapters*". Each of the 4 chapters has its own methodology and outcomes. However, all of their outcomes result in dispute avoidance; which is the core aim of the entire research. It can be seen from Figure 1.3 that the research is applicable to all project phases, where each of its objectives fits directly into one or more phases. Table 1.1 shows multiple aspects of the different chapters including the type of results, the project stage that they apply to, and the type of claims they help in minimizing.

1.5 Research Benefits

This research is distinctive from similar efforts with respect to focus, methods, and purpose. After successful completion, the research contributes to the body of knowledge from multiple qualitative and quantitative angles. First, it provides contractors with an advanced quantitative bid price estimation model that aims at maximizing profits as well as probability of winning. This will prevent contractors attaining a claim-oriented behavior and promote a healthier contractual relationship. Second, it provides a full investigation on OOS work; which helps the industry in understanding the causes and early warning signs of OOS work as well as their impacts. Moreover,

Table 1.1. Mapping of Certain Aspects of the Research.

Dissertation's Technical Chapters →	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Chapter's Name	Decision-theoretic Bidding Model in a Bayesian Framework	Best Practices for Avoiding and Mitigating OOS Work	System Dynamics Modeling of OOS Work	Analysis of Owner's Obligations in Standard Forms of Design-Build Contract
Covers Which Objective?	Objective #1	Objective #3	Objective #4	Objective #2
Relevant to Which Claim/Dispute Factors?	People-related	Task-related	Task-related	Contract-related
Type of Results	Quantitative	Quantitative and Qualitative	Quantitative	Qualitative
Project Stage	Pre-award	Post-award	Post-award	Pre-award
Prevents Claims?	Yes	Yes	--	Yes
Resolves Claims Before Turning into Disputes?	--	--	Yes	Yes
Eventually Prevents Disputes?	Yes	Yes	Yes	Yes

it provides them with a set of preventive and reactive actions in a user-friendly decision-support framework to prevent and mitigate OOS work; thus, leading to prevention of OOS-related claims. Third, the research acts as the first effort to demonstrate the dynamics of OOS work and enable advanced analysis of its direct and indirect impacts. This will benefit project parties in resolving the associated disruption claims before turning into disputes. Finally, the research will enable owners and contractors to have better understanding of the contractual obligations and their corresponding implications. As such, they will draft and administer contracts in a professional manner that minimizes any disputes resulting from un-intentional misunderstandings and intentional misleading contractual drafting practices. To this end, the dispute prevention and mitigation benefits of the different modules will collectively enhance decision making and lead to more successful construction projects. ***The benefits are listed in more depth in each chapter (sections 2.8, 3.10, 4.12, and 5.9), and in the Conclusion chapter (section 6.2)***.

CHAPTER 2:
DECISION-THEORETIC BIDDING MODEL IN A BAYESIAN FRAMEWORK

2.1 Overview

Construction projects, especially public infrastructure ones, are awarded through the process of competitive bidding. In this process, contractors submit their technical offers and bid prices. Several methods could be used to evaluate and select the winning bidder. The typical evaluation method in the US is the low-bid method; where the contractors possessing the required technical qualifications are pooled together and the one with the lowest bid is granted the project. This method ensures that the tax payers money is not wasted. It also forces contractors to implement innovative managerial and technological processes to lower their costs; thus, owners would get the best value of money (Lingard et al. 1998, Tricky 1982).

Examples of other bid evaluation methods include the average-bid and below-average-bid. In the former method, the project contract is awarded to the contractor whose bid price is closest to the average of the bid prices of all bidders (Ioannou and Leu 1993). In the latter method, the project contract is awarded to the contractor whose bid price is closest but below to the average of the bid prices of all bidders (Ioannou and Awwad 2010). However, these two methods are not as commonly used as the low-bid method in both public and private construction. Accordingly, the focus of this chapter is on the low-bid method.

Studying a project's tender documents (i.e. drawings, specifications, conditions, etc.) and preparing a bid package is costly. As such, it is safe to assume that rational contractors are participating in a bid with the goal of winning that bid and getting awarded the contract. Based on that, each contractor i tries to lower its costs and submit a bid price B_i that is hopefully lower than those of other competitors. To come up with this bid price, the contractor would estimate the project's total cost C_i. This total cost is an accumulation of the addition of direct costs (material, equipment, labor, sub-contractors), site overheads (security, rentals, engineering salaries, etc.), head office overheads share, and taxes. The critical decision in obtaining the bid price is what percentage of markup M_i to use. This markup covers the aspired profit and contingencies for the unforeseen risks. As such, the bid price can be formulated as shown in Equation 2.1.

$$B_i = C_i(1 + M_i\%) \qquad \text{Eq. (2.1)}$$

$$Bid\ ratio_i = {}^{B_i}/_{C_i} \qquad \text{Eq. (2.2)}$$

$$Profit = B_i - (C_i + NCC_i) + CC_i \qquad \text{Eq. (2.3)}$$

From the contractor's perspective, a high markup percentage M_i is preferred to earn higher profits. However, increasing the markup will increase the price of the submitted bid B_i, meaning that the probability of other competitors(s) submitting lower bid prices is higher. In other words, a higher markup percentage leads to a lower probability of winning the bid. Alternatively, setting a very low M_i maximizes the probability of winning the bid; however, this would be risky. If a project encounters additional non-compensable costs NCC_i (e.g. costs related to suspension of work due force majeure) higher than the additional compensable costs CC_i (e.g. costs related to delays caused by the employer), this financial gap is covered by the contractor's markup. When this gap gets larger, the contractor's profit gets reduced. If this gap is larger than the markup, then the contractor would have negative profits; meaning that he/she would lose money in the project. In this case, he/she would yield to lowering the quality of the works or attaining claim-oriented behavior to try recovering these losses; resulting in disputes that lead to severe quality, schedule, and cost impacts.

Construction researchers have long investigated how to determine optimal bid prices which maximize both the expected profit and the probability of winning. In summary, the different approaches for tackling this problem could be categorized under game theory, utility theory, and decision theory (Abotaleb and El-adaway 2016). Section 2.3 provides further discussion and literature review on those three directions. In summary, there seems to be an implicit consent among researchers that decision theory models are superior to other models in determining optimal bid prices in relation to enhancing the competitive edge against competitors (Rothkopf 2007).

Decision theory enables calculating the optimum bid value for a contractor in a project based on investigating the past behavior of its competitors when it comes to bid prices. Early decision-theory-based models did not produce accurate results because their underlying assumptions were not realistic (Runeson and Skitmore, 1999). However, researchers have now developed more advanced decision-theoretic models with hybrid modifications to cover the gaps that are described by Runeson and Skitmore (1999). After careful analysis of the literature, we have identified two knowledge gaps that have not been tackled till now. The first gap is that almost all of the current decision-theoretic bidding models require extensive amount of data about the competitors' historical bidding values to provide reliable calculations resulting in optimum bid prices. The second gap is that current models pool the historical bids of competitors without regarding which ones are recent and which ones are old. Then, the models assume that such pool in average governs the future bidding behavior of competitors. Such approach is only valid if each competitor does not change its bidding behavior through time. However, if the competitor has an old bidding behavior (e.g. low markup) that is different than its recent behavior (e.g. high markup), then this dynamic behavior needs to be taken into consideration. Current models do not take the recency of the bid into consideration. As such, an advanced bidding model that considers the dynamic behavior of competing bidders, and at the same time can produces reliable results even in cases of incomplete information of historical bids is required.

2.2 Objective

The objective of this chapter is to develop an advanced model for construction bid price estimation that produces reliable results even if the competitors' data is incomplete and/or if competitors attain dynamic behavior.

2.3 Background on the Current Methods of Approaching Construction Bidding

Studies have handled the construction bidding problem utilizing distinctive game theory, utility theory, and decision theory approaches (Abotaleb and El-adaway 2016). Those theories are discussed in this chapter in the context of construction bidding. Readers should be aware that some of the used terminologies might have different meanings in other contexts and research areas.

2.3.1 *Game Theory in Construction Bidding*

Game theory works best in dynamic bidding games (a.k.a. open auctions). In such setting, competitors know each other's decisions and they can have more than one chance to make up their own decisions until reaching the value that discourages the bidders to bid any lower. However, construction bidding is a static non-cooperative game. A static game is one where each player takes one decision and no player knows the decisions of the others prior to taking his/her own decision (Cachon and Netessine 2004). The use of game theory in this bidding setting is to try to find equilibrium strategies. However, this is an almost-impossible endeavor because no bidder can ascertain the game model nor calculate the utility functions of the other competing players (Rothkopf 2007). This means that game theory cannot be used to efficiently provide a bid price that maximizes both the expected profit and probability of winning. However, game theory has the capability of studying and minimizing the winner's curse (Kagel and Levin 2009). The winner's curse is where the lowest bidder gets awarded the project, but his/her bid price turns out to be less than the project cost (Ahmed et al. 2015). The "curse" here referred to the negative profits that the winner earned. The significant relevant research in construction bidding is that of Ahmed et al. (2015); where they evaluated the level of the winner's curse in contractors working with California Department of Transportation and proposed the symmetric risk neutral Nash equilibrium (SRNNE) function – that was developed originally by Wilson 1977 – to minimize the winner's curse in future similar projects. The SRNNE function, either in single-stage or multi-stage bidding, estimates bid prices that minimizes the chances of falling prey to the winner's curse. However, it cannot be used to maximize the expected profit or the probability of winning. Ho (2005), Ho and Liu (2004), Tan and Suranga (2008), Drew and Skitmore (2006), and Karl (2014) are other examples of utilizing game theory in construction. Although beneficial in other ways, their studies and models do not directly guide contractors in the process of selecting which bid prices to use in their bids.

2.3.2 *Utility Theory in Construction Bidding*

Utility theory in construction bidding is based on the premise that the decision to bid or not to bid and the value of the bid price is made by a contractor depending on various criteria (Dozzi et al. 1996). Examples of such criteria are the level of project complexity, location, duration, presence of competitors, level of competition, contractor's own resources, contractor's financial conditions, completion of designs, and risks involved. Several research works have been made to identify these criteria and study how they impact the bid price value (Wang et al. 2012; Cheng et al. 2011; Dikmen et al. 2007; Liu and Ling 2005; Fayek 1998; Dozzi et al. 1996; Hegzy 1993; Ahmed and Minkarah 1987). Although utility theory models provide helpful insights in simulating the though process of contractors entering bids, they are not able to calculate the probability of winning and the expected profit of the bid prices. At the end of the day, the owner will not award the contractor to a contractor based on how well the contractor studied the project's criteria. The contractor is awarded the project only because he is the qualified one with the least reasonable bid price. What determines whether he has the least or highest bid price is actually the prices of the other competitors. A contractor can use utility theory models and come up with the perfect bid price based on extensive calculations of the utility criteria, but then he could easily lose if just one competitor submits a lower bid. As such, the significant factor in determining winning or losing is the competitor's behavior. This is where decision theory comes in handy.

2.3.3 Decision Theory in Construction Bidding

Decision theory models provide bid price decisions based on the premise that the bid price of the technically qualified competitors is the sole determiner of the winning bidder. Another premise of decision theory is that a bidder can significantly improve his chance of winning by analyzing the bidding pattern of its competitors (Capen et al. 1971). After analyzing the available decision theory models, we can outline its main methodology into three steps that the bidder follows.

1. Step 1 – Assessing the probability of winning each competitor separately: In this step, the contractor entering the bid prices of the competing bidders B_{ij} for each of the past projects j to its own cost estimates C_j in the same projects. From that, the contractor can invert Equation 2.1 and estimate the markup percentages that each competitor used M_{ij}. As such, each competitor will have several markup percentages forming a probability distribution $f_i(r)$; where r is the markup percentage and f is the probability of using such r in a bid. This assumes that the competitor's cost estimate is similar to the contractor's cost estimate. A more realistic assumption is that they are both within a certain value range from each

other. As such, a stochastic element is added so that each markup point M_{ij} is actually a probability distribution of its own, and f is the summation of all these distributions. After forming f, the probability of winning a bid $P_i(r)$ against the competitor at a certain percentage of markup is the probability of the competitor submitting a bid with a higher markup as shown in Equation 2.4.

$$P_i(r) = \int_r^\infty f_i(r)\, dr \qquad \text{Eq. (2.4)}$$

2. Step 2 – Calculating the probability of winning a bid having all competing bidders: Friedman (1956) and Gates (1967) developed the most famous formulations for calculating the probability of wining all competitors using the probability of winning each competitor separately. Equation 2.5 shows Friedman's formula and Equation 2.6 shows Gates' formula, where $P_i(r)$ is the probability of winning competitor i at markup percentage r, n is the number of competitors, and $P_{win}(r)$ is the probability of winning all competitors

$$P_{win}(r) = \prod_{i=1}^{n} P_i(r) \qquad \text{Eq. (2.5)}$$

$$P_{win}(r) = \left[\sum_{i=1}^{n}\left(\frac{1-P_i(r)}{P_i(r)}\right) + 1\right]^{-1} \qquad \text{Eq. (2.6)}$$

Friedman developed his function assuming that bids of the competitors are statistically independent, while Gates views them as dependent. In reality, bids of competitors are neither completely independent not completely dependent, but rather a combination of both that differs from one project to another (King and Mercer 1987). The difference in the resulting $P_{win}(r)$ between Friedman and Gates' equation is minor. So, exciting efforts to find out the exact level of statistical dependence in each project would be impractical.

There is no consensus on which of the models is more accurate; Friedman's or Gates'. However, both models are widely accepted in the literature and they are still used heavily (Crowley 2000). After conducting several statistical tests and case studies, Crowly (2000) concluded that "*both models are simultaneously correct and incorrect. Friedman's model is theoretically correct, yet the bid problem is incorrectly specified. Gates's model is practically correct, yet the formula is incorrectly specified*." From an industry perspective, according to Sparks (1999), Friedman's model results in a lower bid price that that provided by Gate's model. Accordingly, Friedman's model aids the contractor in winning more projects than Gate's model. But, it does not bring high long-term profits as those brought by the model of Gates. Accordingly, we cannot say that one model is superior to the other. Both models are heavily used, and that determining which of them to use depends on the bidder's situation. Both models were used in this research to suit all schools of thought. The research contribution in this chapter lies in the first step rather than this one.

3. Step 3 – Optimizing the choice of the bid price: An expected profit function is used to determine the probability of winning the competitors at each percentage of the markup. This function is straight-forward, one-dimensional and is abstracted from an optimality expected value function (Rothkopf 2007, Gilboa 2009). An expected value is the sum of all possible outcomes multiplied by the value of these outcomes. As such, the expected profit is the markup percentage multiplied by the probability of winning at that markup as written in Equation 2.7. The optimum markup percentage "r" is the one at which the expected profit is at its maximum. After obtaining r from Equation 2.7, the bidder would use this r it in Equation 2.1 to come up with the optimal bid price with the combination of the highest profit and probability of winning. It shall be noted the r in Equation 2.7 is M in Equation 2.1.

$$EP(r) = r.P_{win}(r) \qquad \text{Eq. (2.7)}$$

The main difficulties utilizing traditional decision theory is the need for unrealistically large amount of data for outputting statistically satisfactory results (Skitmore and Pemberton 1994). Several studies have attempted to tackle this by adding hybrid techniques into the traditional decision-theoretic concepts. For example, a model for estimating project costs and bid prices using a multivariate approach was proposed by Skitmore (1991). This model was later extended by Skitmore and Pemberton (1994) by incorporating techniques that augment the data points by several orders of magnitude to strengthen the statistical soundness. Christodoulou (2004) combined between decision theory and utility theory through a computational approach that uses multidimensional risk analysis algorithms and neurofuzzy systems. Another notable hybrid model is the one developed by Yuan (2011). Yuan's model uses probabilistic analysis and Bayesian methods to analyze the correlation between past bids of competing bidders to determine the optimal bid prices for future projects. Other significant relevant works utilizing decision theory (either as the main premise or in combination with other techniques) are the ones of Chao and Kuo (2017), Lo and Yuan (2012), Skitmore et al (2007), Cooper et al (2005), Touran (1993, 2003), Lo and Lam (2001a, 2001b), Ranasinghe (2000), Winkler and Brooks (1980), Dixie (1974), Rosenshine (1972), and Stark (1968).

In spite of the above-mentioned endeavors, current models utilizing decision theory still face two limitations that need to be addressed. The first limitation is that they require extensive amount of data regarding competitors' past bidding behavior to be able to produce reliable forecasts about their future bids. The second limitation is that these models do not distinguish between the recent and the old bids of competitors. Instead, they pool all of the bids of a competitor and perform statistical analysis on that pool. This means that all historical points have the same weight. This is misleading in case the data that we have is too old and does not represent the current behavior of competitors. It also poses problems if the competitors attain dynamic behavior; where their bidding behavior changes with time.

The model developed and presented in this chapter covers the above-mentioned limitations through incorporating Bayesian statistics into the decision theory process. Bayesian statistics enables the differentiation between different sets of observations (old and recent) of competitors' bids. It also has mechanisms that allow filling missing data points with data coming from educated beliefs. An educated belief is formed by the experience of the user and other analysis that is presented later in the chapter. In short, although the concept of educated belief is not used in conventional statistics, it is used in Bayesian statistics and considered legitimate and reliable in Bayesian premises similar to the one that characterizes the developed model in this chapter (Stevens 2009, Bolstad 2007, Press and Press 1989). Accordingly, the developed model can determine the optimal bid price in cases of incomplete information and/or dynamic behavior of competitors.

2.4 Background on the Used Statistical Concepts

2.4.1 Background on Bayesian Statistics

The two major approaches to statistical inferences are frequentist statistics (a.k.a. conventional statistics) and Bayesian statistics. When uncertainty is present, Bayseian statistics provides better inferences than frequentist statistics in decision-making applications (Bernardo 2011). Bayeseian statistics also has the ability to integrate scientific hypothesis, or educated ‘beliefs’, in the analysis. It does so through the means of the “prior distributions” when the available data is not sufficient to produce sound statistical inferences using the conventional frequentist concepts (Bolstad 2007, Press and Press 1989). “*A salient feature of Bayesian inference is its ability to incorporate information from a variety of sources into the inference model, via the prior distribution … Done properly, Bayesian inference integrates old information and new information into an evidence-based state-of-knowledge distribution*” Kelly (2010). According to Abotaleb and El-adaway (2016), “*Bayesian statistics interprets probability as a rational, conditional measure of uncertainty; where statistical inference about a quantity of interest is described as the modification of the uncertainty about its value in light of evidence (Bernardo 2011). Such modification is made according Bayes’ equation*”. Bayes’ equation is presented in Equation 2.8. In the equation, the proportionality symbol $\propto$ means that right-hand side must be normalized; in other ords, if we integrate it over its full support, the results should be equal to one.

$$p(\theta|D) \propto f(D|\theta)\pi(\theta) \qquad \text{Eq. (2.8)}$$

In Bayesian statistics, we collect information about the unknown parameters of interest from two sources of information; unlike in frequentist statistics where only one source of information is used. The two sources are called (1) the prior distribution and (2) the likelihood function. The prior distribution $\pi(\theta)$ represents the original prior data based on the available information to the investigator (Abotaleb and El-adaway 2016). The likelihood function $f(D|\theta)$ is the probability of observing the data D being conditional on the values of the parameter θ (Abotaleb and El-adaway 2016). It represents the observed behavior of uncertainty. The posterior function $p(\theta|D)$ is calculated according Bayes’ equation (Equation 2.8). It provides a weighted compromise between the likelihood data and the prior information while keeping the statistical integrity of the environment (Stevens 2009). The posterior distribution is the conditional distribution of the parameter of interest given the data. In this research, the parameter of interest would be the markup % distribution of each competing bidder.

2.4.2 Background on Markov Chain Monte Carlo Methods

There are heuristics and software functions that enable sampling variable from known continuous probability distributions such as the normal, Gamma, Beta, and Weibull distributions. However, sampling from non-parametric probability distributions requires different techniques and such techniques are not readily available in software packages. For that, Markov Chain Monte Carlo (MCMC) methods are used. From its name, MCMC combines between Markov Chains and Monte Carlo methods. A Markov Chain is a sequence of states – or values - obtained through a stochastic procedure; where each state X_n is dependent on its previous state X_{n-1} (Serfozo 2009).

MCMC is a technique for sampling – generating independent and identically distributed *iid* variables - from any probability density function PDF, named the target distribution. The target distribution could be parametric or non-parametric. MCMC does so through drawing samples from a parametric PDF – named the proposal distribution – and performing acceptance/rejection procedures on such samples to reach the target distribution (Robert and Casella 2010). The drawn samples are Markov chains, meaning that each draw depends on the preceding draw. The one condition for MCMC techniques to work is that the generated Markov chain must be ergodic (Gilks 2005). A Markov Chain is ergodic when it is *aperiodic*, *irreducible*, and *positive recurrent* (Abotaleb and El-adaway 2016). An *aperiodic* Markov chain is one that does not repeat an identical cycle of states. A *positive recurrent* Markov chain is one the that has a finite expected return time from a state to the same. An *irreducible* Markov chain is one where the sequence X_n has a positive probability of reaching any region of the state-space (Robert and Casella 2009). There are two widely used techniques for MCMC, namely the Metropolis-Hastings algorithm and the Gibbs sampling algorithm.

Named after Metropolis et al. (1953) and Hastings (1970), the Metropolis-Hastings algorithm samples from a proposal density $q(y|x)$ that is easy to simulate and performs acceptance/rejection processes on the samples so that the final samples have the behavior as if they were drawn from the target probability density f(Robert and Casella 2009). There are two conditions to successfully perform the algorithm according to Robert (2015): (1) the ratio of $f(y)$ to $q(y|x)$ [which is $f(y)/q(y|x)$] has to be known up to a constant independent of x, and (2) $q(\cdot\,|x)$ has a wider support than f. As such, constructing a Markov transition kernel $X_0, \ldots, X_T$ that abides by the target probability function follows the following steps: Start with an initial random variable X_t. This will be the initial variable in the Marcov Kernel. From this variable, generate $Y_t \sim q(y|x_t)$. From X_t and Y_t, obtain X_{t+1}; where,

$$X_{t+1} = \begin{cases} Y_t & \text{with probability} \quad \rho(x_t, Y_t) \\ X_t & \text{with probability } 1 - \rho(x_t, Y_t) \end{cases} \qquad \text{Eq. (2.9)}$$

$$\rho(x, y) = \min\left\{\frac{f(y)}{f(x)}\frac{q(x|y)}{q(y|x)}\,, 1\right\} \qquad \text{Eq. (2.10)}$$

The resulting chain $X_0, \ldots, X_T$ can be considered a sample of f. Due to the Markovian nature of the simulation, the first values are usually removed from the samples as *burn-in* because they are highly dependent on the starting value X_0 (Abotaleb and El-adaway 2016). Once they are removed, the Markov chain could be considered as equivalent to a standard *iid* simulation (draws) from f (Robert 2015).

The second technique - Gibbs sampling - is used for the same purpose as the Metropolis-Hastings algorithm, and it has its advantages especially in high dimensional multivariate analysis (Abotaleb and El-adaway 2016). However, it requires additional data about the relationship between the target and the proposal distributions that may not be present. For example, in Gibbs sampling, to sample from a joint distribution $p(\theta_1, \ldots, \theta_k)$, one must know the full conditional distributions for each parameter. The full conditional distribution is the distribution of the parameter conditional on the known information and all the other parameters $p\left(\theta_j|\theta_{-j},\ y\right)$. In the scope of this research, such information is not available. Moreover, according to Gilks (2005), if the target function is not following a standard parametric probability distribution such as the normal distribution, Gibbs sampling becomes impractical due to the lack of conjugacy in this case. For that, we decided to use the Metropolis-Hastings algorithm since it is more generic, flexible, and does not require such complex data (i.e. conditionals and conjugates).

2.4.3 Background on the Kolmogorov-Smirnov Test

The one-sample Kolmogorov-Smirnov (K-S) test is a nonparametric statistical test that examines whether a sample comes from a specific probability distribution. This test is used in this research to measure the goodness of fit, which is one of its main uses (Wilcox 2005). The K-S test can be outlines as follows (Marsaglia 2003):

1. A number N of sample data points is present. These points are ordered based on their value. As such, the sample data points become ordered as follows $X_1, \ldots, X_n$. From those points we form an empirical cumulative distribution function $ECDF$. The $ECDF$ is defined as $E_N = n(i)/N$, where $n(i)$ is the number of points less than X_i. The $ECDF$ is the function that represents the sample.
2. The reference cumulative distribution function $RCDF$ is the probability distribution that we want to test whether the sample came from it or not.
3. Both the $ECDF$ and the $RCDF$ are plotted and compared to one another; where the $RCDF$ acts as the reference. The maximum distance between the $ECDF$ and the $RCDF$ is measured.
4. The K-S test is defined by:
    a. The test statistic D is defined as shown in Equation 2.11.

    $$D = \max_{1 \le i \le N} \left(F(X_i) - \frac{i-1}{N}, \frac{i}{N} - F(X_i) \right) \qquad \text{Eq. (2.11)}$$

    where F is the theoretical cumulative distribution of the $ECDF$. Note that the $ECDF$ must be a continuous distribution.

    b. The null hypothesis H_0: the points $X_1, \ldots, X_n$ are drawn from a probability distribution that is different from the reference distribution $RCDF$.

    c. The alternative hypothesis H_A: the points $X_1, \ldots, X_n$ are drawn from the $RCDF$.

5. There are K-S tables that correspond the resulting test statistic D with p-values. As in other statistical tests, if the p-value is less than the anticipated significance level α, the null hypothesis is rejected. Otherwise, there would be no evidence to reject the null hypothesis.

The most common value for α is 0.05 (Nuzzo 2014). As such, if the p-value is less than 0.05, then we could conclude that statistical evidence indicate a significant difference between the $ECDF$ and the $RCDF$ (no good fit). Otherwise, we could conclude an acceptable goodness of fit.

2.5 Model Development

A multi-step methodology is used in developing the model. In the first three steps, we developed equations and heuristics to fitting the competitors' historical data and forming their prior distributions. In the fourth step, we developed a formulation to represent the stochastic likelihood functions of competitors through their recent historical observations. The fifth step is concerned with forming the posterior distributions of the competitors that will be used in the subsequent steps for inferences. As such, the first five steps represent the Bayesian part of the model. The sixth and seventh steps are the decision-theory part of the model. They are concerned with using the posterior distributions of the competitors and calculating the probabilities of winning against them, then selecting the optimum markup percentage that maximizes the expected profit function. Figure 2.1 demonstrates how Bayesian statistics and Decision Theory are integrated in this research.

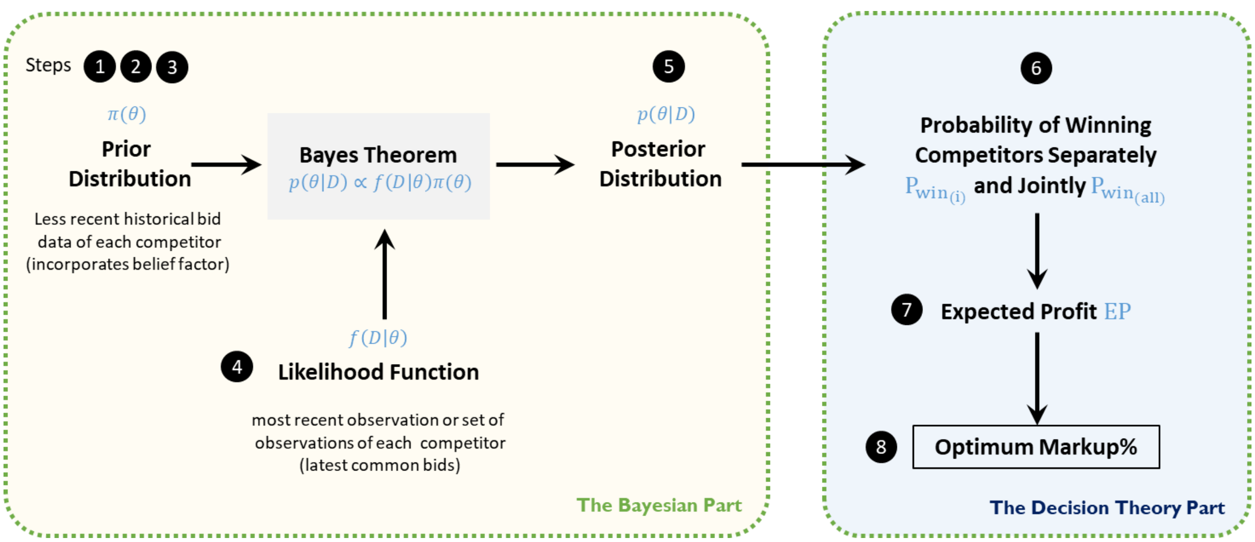


Figure 2.1. The Broad View of the Combination of Bayesian Statistics and Decision Theory in the Research.

To explain how Bayesian statistics is used in the context of this research, the past bid price information of competitors are not going to be considered of equal natures as generally treated in frequentist statistical approaches. Instead, the more recent observations will have a substantial role in influencing the statistical inferences of future expectations more than the role of the less recent ones. The older historical data will form the prior distribution $\pi(\theta)$. If this data is incomplete or unavailable for a competitor, a firm can use the concept of the "average bidder" that is established by Friedman (1956). The likelihood function $f(D|\theta)$ will be formed from the recent observation or group of observations of competitors. The stochastic variability between the contractor's cost estimation and the competitors' cost estimation in each of the available data points is considered in both the prior distribution and likelihood function. The posterior distribution is then formed using Bayes theory to take both sources of information into consideration and enable us to make forecasts based on that.

2.5.1 The First Step: Creating the Preliminary Distribution Density Functions (PDDF)

One important exercise that is made by contractors who wish to increase their chances of winning bids is keeping record of the competitors' past bids. This is possible in several public projects and some private projects. However, in most private projects, owners do not disclose the bid prices of the bidders. The perfect situation for a contractor is to know the markup percentages M_{ij} of its competitors directly (i is the competitor number and j is the past bid number). However, this information is very difficult to obtain. No contractor will reveal its markup. What is more realistic is that contractors would know the previous bid prices B_{ij} of their competitors. Such bid prices are functions of the competitors' cost estimate C_{ij} and their markup percentage M_{ij}; which are both unknown to the contractor. However, there is an assumption that is made that the contractor's own cost estimate C_j for a project j is equal the cost estimate of the competitor C_{ij} in that project plus or minus some stochastic variable. By knowing this C_{ij}, the value of M_{ij} can be obtained. However, given the uncertainty about the variability between the contractor's own cost estimate and the competitors' cost estimate, each data point of a historic bid price of a competitor provides the contractor with probability distribution of markup percentages rather than discrete points. So, for example, if a contractor estimated that a project will cost \$1 Million and the competitor submitted a bid price of \$1.1 M, the discrete solution would be that the competitor's markup is (1.1 – 1)/1 =

10% and the probabilistic solution that is utilized in this research is that the competitor's markup is a *range* defined by the normal distribution with mean 10% and a standard deviation of a certain number. Justification for using the normal distribution and the meaning of the standard deviation are presented later.

All of the old historical bids of a competitor i are collected and used in a function that we developed and called the preliminary distribution density function (PDDF). This function, referred to as pd_i(r) in Equation 2.12, is simply the summation of all probability density functions of the markups of the competitor. The function also has another term that makes up for data incompleteness and irrational data points. The pd_i(r) function is presented in Equation 2.12. In the function, the support of r is all rational positive numbers, meaning that $r \in (0, \infty)$. The term $N(r|x, y)$ represents the normal distribution PDF where x is the mean and y is the standard deviation. The term $\Gamma(r|x, y)$ represents the Gamma distribution PDF where x is the shape and y is the rate. B_{ij} is the bid price of competitor i in bid j. C_j is the contractor's own cost estimate of the project in bid j. σ_{ij} is a variable representing the stochastic variability between the contractor's own cost estimate and the competitor i's cost estimate in of the project in bid j. So, if $\sigma_{ij} = 1$, this means that the contractor believes that the different between his own cost estimate and the competitor's cost estimate follows a standard normal distribution with a mean of 0 with and a standard deviation of 1. The model is flexible to suit a difference value of σ_{ij} in each bid and for each competitor. Higher values of σ_{ij} represent lower uncertainty when it comes to the competitor's cost estimate.

$$pd_i(\mathrm{r}) \propto \sum_{j=1}^{n_i} \left[N\left(r \middle| \frac{B_{ij} \times 100}{C_j} - 100, \sigma_{ij}\right)\left(1 - \emptyset_{ij}\right) + \Gamma\left(r|\alpha_{ij}, \beta_{ij}\right)\left(\emptyset_{ij}\right)\right] \quad \text{Eq. (2.12)}$$

$$N(r|x, y) = \frac{1}{y\sqrt{2\pi}} e^{-\frac{(r-x)^2}{2y^2}} \quad \text{Eq. (2.13)}$$

$$\Gamma(r|x, y) = \frac{y^x}{\int_0^\infty r^{x-1} e^{-r}} r^{a-1} e^{-yr} \quad \text{Eq. (2.14)}$$

From several possible probability distributions, the normal distribution is selected to represent each data point because it has been frequently used in similar bidding settings and there seems to be a consensus on its efficiency in incorporating uncertainty in such settings (Carr 1983, Ioannou and Leu 1993, Awwad and Ioannou 2010). In Equation 2.12, there is a binary variable $\emptyset_{ij}$ that makes the contractor either use the normal distribution part or the Gamma distribution part of the equation for the competitor's data point. If $\emptyset_{ij}$ is equal to 0, the normal distribution part of the equation is used, and the Gamma distribution part is not use (because it will be multiplied by 0). If $\emptyset_{ij}$ is equal to 1, the opposite will happen. The Gamma part of the equation is the term that takes care of data incompleteness or irrationality. It is the part where the contractor uses its educated belief. The bid ratio between the bid price of the competitor and the own cost estimate of the contractor determines the value of $\emptyset_{ij}$. For any historical bid, it is logical that the B_{ij}/C_i would be higher than 1. However, in rare cases, B_{ij}/C_i would be lower than 1. This could mean one of the following: (1) either the competitor is bidding with a negative markup, or (2) for some reason, the competitor's cost estimate is much lower than the contractor's own cost estimate. The first interpretation is not logical, or at least not considered in this model. The model is based on the premise that all bidders enter bids with positive profits. The second interpretation is plausible. In this case, it is not possible to estimate the competitor's markup using the normal distribution part of the equation. If the normal distribution part was used, it would have a negative r. The r needs to be always on the positive side of the number line. In this case, the contractor uses its experience to estimate the probability of markup percentages that the competitor used through the Gamma distribution. The Gamma distribution is used here because it has a positive support (r is always positive), and because it can assume multiple ranges of shapes, from normal to exponential (Hazewinkel 2001).

For a data point that utilizes the Gamma distribution, it is up to the contractor to specify the distribution's parameters α_{ij} and β_{ij}. Both parameters are non-zero, non-negative values that control the shape of the distribution in terms of skewness, peak location, and peak width. If B_{ij}/C_i is less than 1 (activating the Gamma part of Equation 2.12) and the contractors has information that the competitor i in bid j was bidding with low markup, the contractor might opt to use parameter like $\alpha_{ij} = 2$ and $\beta_{ij} = 1$. If the contractor hypothesizes that the competitors was bidding with a high markup, he much opt to use parameters like $\alpha_{ij} = 7$ and $\beta_{ij} = 1$. Figure 2.2 demonstrates the effects of the Gamma parameters on the shape of the distribution. Note that the support is always in the positive r region. This ensures that the preliminary distribution density function has always positive support.

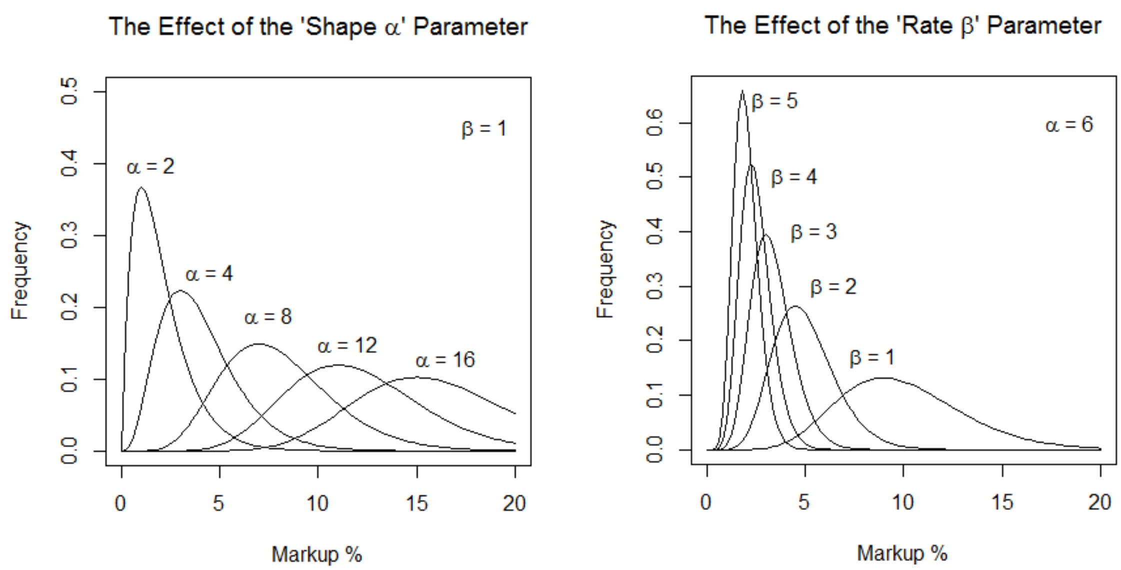


Figure 2.2. The Effect of the Gamma Parameters on the Shape of the Distribution.

In Equation 2.12, the term n_i represents the number of historical bids that are used in forming the preliminary distribution density function for competitor i. We must note that this does not include all historical bids. It includes only those historical bids the take place before the *latest common bids*; which are explained in section 2.5.5 when we are discussing the likelihood function. Also, if the full set of historical bids of a competitor is missing, then steps 1 to 3 are not needed. The contractor would use the "average bidder" concept and use a prior function (see section 2.5.4 for more details) that is the average of all prior functions of the other competitors. The contractor could also use any probability distribution to represent the prior function of that competitor but at his own risk. Another note is that the right-hand side of Equation 2.12 must be normalized. As such, the integration of $pd_i(\mathrm{r})$ should yield to 1.

2.5.2 *The Second Step: Using Markov Chain Monte Carlo to Sample from the PDDF*

After the PDDF is formed for each competitor, data points are sampled from each PDDF using the Metropolis Hastings algorithm for MCMC because the PDDF is not a simple parametric probability density function. Because of the powerful computing capabilities of current personal computers, the recommended number of draws S for each competitor is 10,000; from those, the first 1,000 simulations are considered burn-ins (meaning they are neglected and not part of the final Markov kernel). The initial random variable in the Markov kernel X_0 has a value of 1 in the model. No matter what this number is, the chain will converge; but the speed of convergence will depend on how close or far the initial value is to/from the range of the target distribution (Robert 2015). The target distribution here is the PDDF. A value of $X_0 = 1$ (meaning a markup of 1%) is always within the range of the target distribution. The Metropolis-Hastings algorithm is discussed in detail in section 2.4.2.

A simplification in the Metropolis Hastings algorithm is made by using "random walk". The random walk still allows for exploring local random variables in the support of the target function without jeopardizing the ergodic properties of the chain (Abotaleb and El-adaway 2016). To apply the random walk in this model, the random variable Y_t (Equation 2.9) is obtained as a function of X_{t-1} as shown in Equation 2.15. In the equation, ε_t is a random number with a normal distribution with a mean of 0 and a standard deviation of 2 (Equation 2.16). As such, in each draw, the value of Y_t is generated from the normal distribution and added to the preceding to the preceding X_{t-1}.

$$Y_t = X_{t-1} + \varepsilon_t \qquad \text{Eq. (2.15)}$$

$$\varepsilon_t \sim N(0,2) \qquad \text{Eq. (2.16)}$$

The use of the random walk simplifies the probability of acceptance (Equation 2.10) by removing the term $q(x|y)/q(y|x)$, because the random walk makes $q(x|y) = q(y|x)$. As such the acceptance probability becomes as follows (Equation 2.17)

$$\rho(x,y) = \min\left\{\frac{f(y)}{f(x)}, 1\right\} \qquad \text{Eq. (2.17)}$$

An acceptance rate higher than 23.4% indicates that the chain is converging well, and that the candidate function is suitable for sampling and leading to variables having a distribution similar to the target distribution. Figure 2.3 demonstrates the steps of sampling from the PDDF function for each competitor separately.

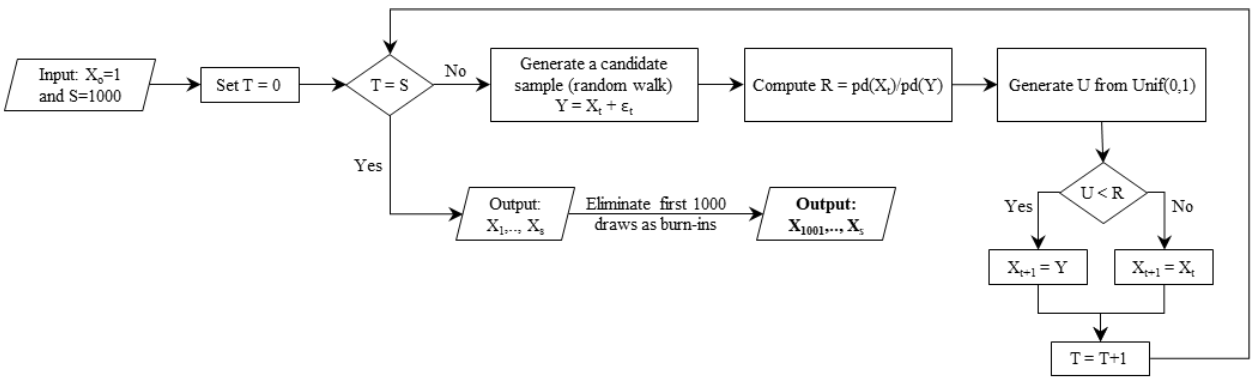


Figure 2.3. The Procedure of the Metropolis-Hastings Algorithm Used in the Model.

2.5.3 The Third Step: Fitting the Sampled Data Points into Parametric Probability Distributions

For each competitor, the Markov kernel that is produced in the second step (section 2.5.2) represents the set of markups for such competitors. Those markups should be fitted in parametric probability density functions (PDF) such as the normal distribution. Selecting which parametric PDF fits the kernel of each competitor is an endeavor that needs experience and judgement (Pouillot and Delignette-Muller 2010). It also requires doing iterations of choosing distribution, estimating parameters, and evaluating the quality of fit (Pouillot and Delignette-Muller 2010). To minimize subjectivity, some statistical tests were developed by others. The following paragraphs present a methodology for fitting the sampled data points of each competitor into parametric PDFs. The paragraphs explain the procedure for doing so for one competitor. These procedures should be followed for each competitor separately. As such, each competitor i at the end will have its data points $[X_{1,001}, X_{1,002} \ ..., X_{10,000}]_i$ fitted into one PDF.

First, a histogram of the data points $[X_{1,001}, X_{1,002} \ \dots, X_{10,000}]_i$ is plotted. If the histogram has zero or one significant peak, this means that the data can be fitted using the traditional parametric PDFs such as the normal distribution and the Gamma distribution. To know which distribution fits the data points, the Cullen and Frey graph is plotted. Such graph shows how close the distribution of the data points to a set of pre-defined parametric PDFs. It is able to provide this closeness based on calculations comparing the square of skewness and kurtosis of the data points and the parametric distributions (Pouillot and Delignette-Muller 2010, Cullen and Frey 1999. Figure 2.4 shows the Cullen and Frey graph for a sample set of data points. In this Figure, the Cullen and Frey graph indicates that the data points (represented in the blue circle) have a distribution close to the normal and Gamma distributions.

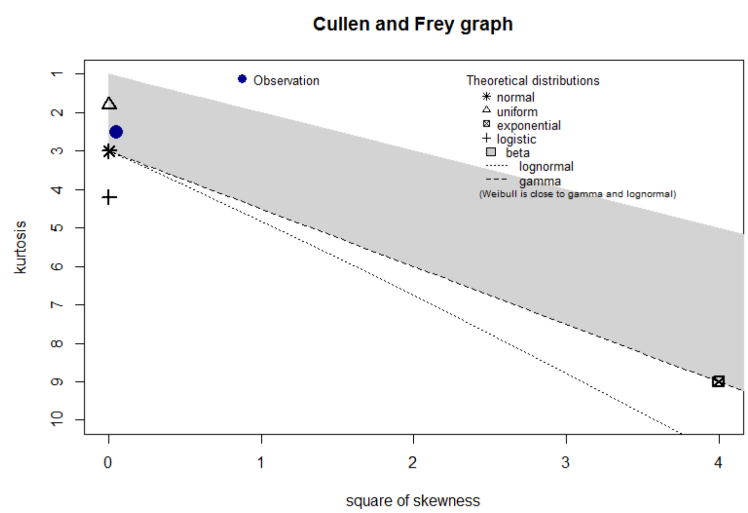


Figure 2.4. The Cullen and Frey Graph for a Sample Set of Data Points.

After that, the distributions that are closest to the data points are selected to be tested. But before testing, the distributions' parameters need to be known. For example, if the Cullen and Frey graph indicated that the data set is close to both the normal and the Gamma distribution, what is the mean and standard deviation of that normal distribution? And what is the shape and rate of that Gamma distribution? Software packages for finding these parameters are available.

After fitting the data points to the multiple possible distributions, the question here is which distribution best fits the data points? To answer this question, the Kolmogorov-Smirnov (K-S) test is used on each of the possible distributions to evaluate the quality of fitness. A p-value higher than 0.05 indicates that the distribution fits the data set. So, if multiple distributions have p-value more than 0.05, we select the one with the higher p-value.

In case the histogram of the data set has more than one significant peak, then we do not use the Cullen and Frey graph or the K-S test because they are only limited to the traditional distributions that have one or no peak. In this case, the data points are fitted directly using logspline fitting; at which a function is formed from a space of linearly tailed cubic splines with a finite number of pre-specified knots (Kooperberg and Stone 1991). Kooperberg and Stone (1991) provide more details on the mathematical formulations of logspline fitting. As this research is concerned, there are software packages that perform such fitting with a single line of code.

It should be noted that the used programming language in this model is R. It has packages that enable plotting the Cullen and Frey graph, finding the parameters that best fit the data sets to PDFs, and performing the K-S test for PDF evaluation.

2.5.4 The Fourth Step: Setting the Prior Function for Each Competitor

For each competitor i, the probability distribution that fits its data points (by passing the K-S test or if its is using logspline fitting) is set as the prior distribution $\pi(\theta)_i$ of the competitor. This prior distribution must be normalized; meaning that its integration over its support should be equal to one. Its support should be only ranging in the positive rational numbers.

If the contractor does not have sufficient historical bids to go through the first three steps and form the $\pi(\theta)_i$ for a certain competitor, it would form such $\pi(\theta)_i$ through utilizing the concept of the average bidder or based its expert judgement. The “average bidder” concept was originally developed by Friedman (1956). It has been acknowledged by other researchers such as Capen et al. (1971), Hanssmann, and Rivett (1959), and Sparks (1999). In short, if the contractor uses the average bidder concept, he would use all historical records of the other competitors and use them as if the belong to the competitor with the missing information. The contractor could opt to use its expert judgement or a minimally informative distribution instead of the average bidder method to form the $\pi(\theta)_i$. Examples of a minimally informative distribution include the normal distribution with a large standard deviation, the Gama distribution with a small rate, and the uniform distribution with a wide range (Abotaleb and El-adaway 2016). Although this could be considered subjective, Bayesian statistics is able to incorporate such subjectivity, especially if the prior distribution is minimally informative, without putting the statistical integrity of the model at risk (Kelly 2010). Despite that, still, having objective information with minimal subjectivity will enhance the credibility of the results.

2.5.5 The Fifth Step: Creating the Likelihood Function for Each Competitor

The latest common bid value(s) for each competitor is used to create its likelihood function $f(D|\theta)_i$. The latest common bids are defined as the most recent bids of the competitor, and also they share commonality with the project in hand. This commonality could be in the project conditions such as the project type, location, risk, and cost. The most important commonality is recency; meaning that the historical bids that are used in the likelihood function for a competitor must be the most recent ones and must be made within a short period of time between one another. These commonalities strengthen the credibility of the results given the salient conditional features of Bayesian statistics. If there are no commonality, then only the latest historical bid is used in the likelihood function. The likelihood function $f(D|\theta)_i$ for competitor i is shown in Equation 2.18. It is similar to the $pd_i(\mathrm{r})$ function in Equation 2.12. The only difference is that the historical bids used in the $f(D|\theta)_i$ are the latest common bids. The other older bids are used in the $pd_i(\mathrm{r})$. As such, in Equation 2.18, K is the number of latest common bids. Similar to the $pd_i(\mathrm{r})$ function, the right-hand side of the $f(D|\theta)_i$ function must be normalized; hence, the "∝" symbol. Similar to the preliminary distribution density function, the binary variable $\emptyset_{ik}$ in the likelihood function acts as a switch for deciding on whether to use the normal distribution side or the Gamma distribution side of the equation. If B_{ij}/C_i is greater than, then $\emptyset_{ij} = 0$. Oppositely, if B_{ij}/C_i is less than or equal to 1, then $\emptyset_{ij} = 1$ and the contractor would yield to educated belief to estimate the parameters of the Gamma function as mentioned in Section 2.5.2.

$$f(D|\theta)_i \propto \sum_{k=1}^{K} \left[N\left(r \middle| \frac{Z_{ik} \times 100}{C_k} - 100, \sigma_{ik}\right)(1 - \emptyset_{ik}) + +\Gamma(r|\alpha_{ik}, \beta_{ik})(\emptyset_{ik}) \right] \quad \text{Eq. (2.18)}$$

2.5.6 The Sixth Step: Calculating the Posterior Distribution for Each Competitor

After forming the prior distribution $\pi(\theta)_i$ and the likelihood function$f(D|\theta)_i$ of each competitor, the posterior distribution $p(\theta|D)_i$ is calculated using Bayes theorym shown in Equation 2.8 by simply multiplying $\pi(\theta)_i$ by $f(D|\theta)_i$ and normalizing the result. All inferences are then made from this posterior distribution. The rest of the steps represent the decision-theory part of the model.

2.5.7 The Seventh Step: Estimating the Probability of Winning Against Competitors Separately and Jointly

Starting here, the term of the posterior distribution will be renamed to match the terms in decision theory. As such, we will set $f_i(r) = p(\theta|D)_i$. From here, the rest of the decision-theory steps will be followed. Accordingly, Equation 2.4 will be used to calculate the probability of winning competitor i at each percentage of markup r. After that, either Equation 2.5 or 2.6 is used to calculate the probability of winning all competitors (depending on whether the contractor prefers using Friedman or Gates' formula).

2.5.8 The Eighth Step: Determining the Optimal Markup

The expected profit $EP(r)$ at any r is obtained by multiplying the markup percentage r by the probability of winning at that markup as shown in Equation 2.7. The markup percentage that yields the highest expected profit is the optimum markup that maximizes the probability of winning and the gained profits. The bid value that the contractor should use in the project is as follows:

$$Bid\ Price = Project\ Cost\ Estimate(1 + Optimum\ Markup\%) \qquad \text{Eq. (2.19)}$$

2.5.9 Using the Developed Model

A flowchart is developed to guide contractors and researchers who wish to use the model. The flow chart is presented in Figure 2.5. It consists of systematic steps that should be followed sequentially. The flowchart also has what-if scenarios to suit all types of data availability. All details regarding the steps in the flowchart are mentioned in sections 2.5.1 to 2.5.8. It should be noted that the model is not an actual software, but rather a series of heuristics and equations

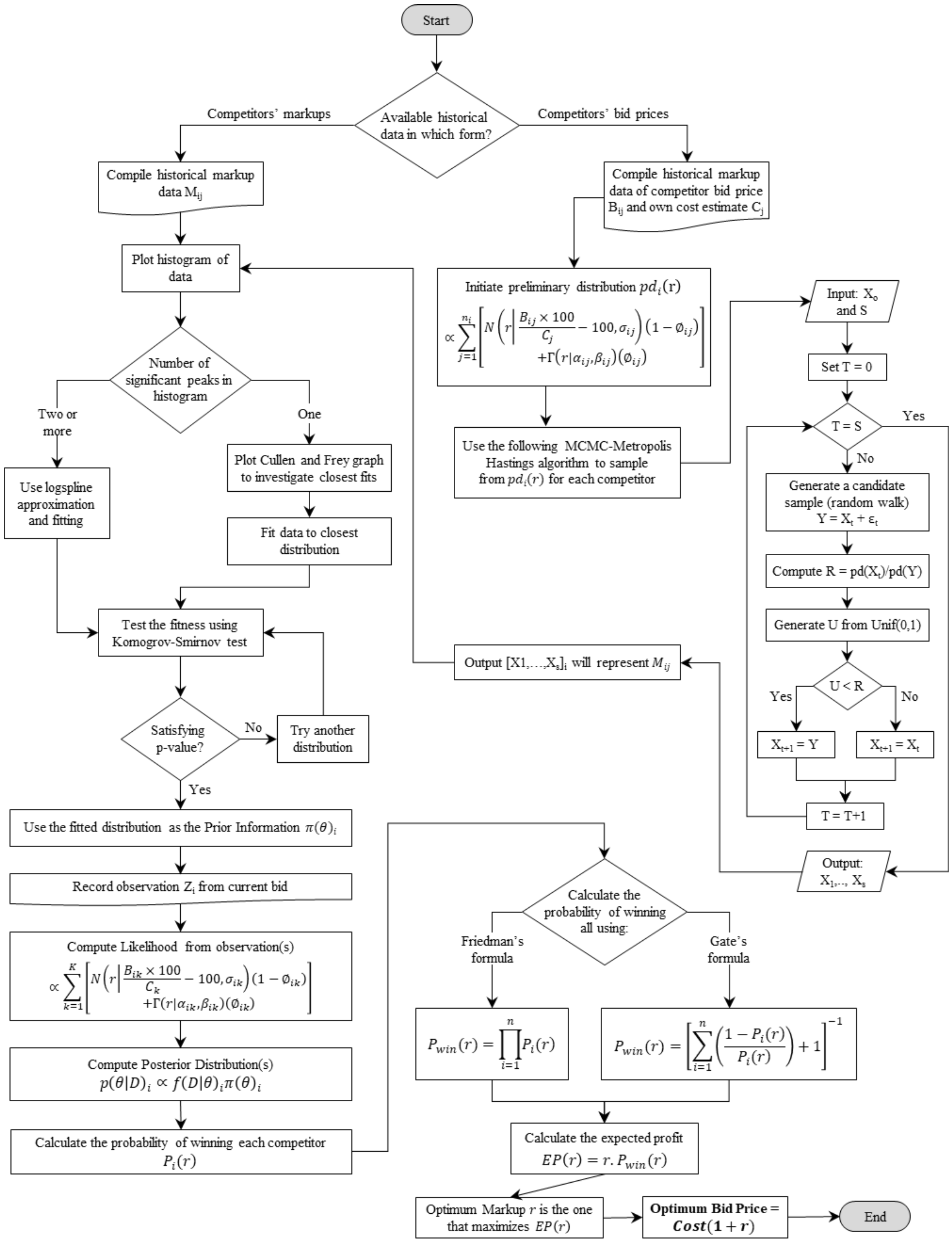


Figure 2.5. Flowchart for Using the Developed Model.

developed solely for the purpose of estimating the optimal bid price for a project based on analysis of historical bids of competitors.

It shall be noted that the bid price, either in this model or in other models in the literature, does not provide any guarantee that the contractor will win the bid.

It is not likely for a contractor to identify its competitors in a future project. Such information is revealed only in the bid opening session. However, the model assumed that contractor has knowledge of which competitors are bidding against it in a newly-advertised project. This assumption has been used by several similar bidding models and is considered a reasonable abstraction to reality because usually firms in an area can have good guesses of whom are competing in their areas (Boughton 1987). If the contractor has absolutely no knowledge of who is bidding against it, then neither this model nor any other model in the literature will be of any use.

2.6 Case Studies

2.6.1 Description of the Case Studies

To demonstrate its use and applicability, the developed model was used on two case studies. The data of both case studies came from the literature for two main reasons: (1) to facilitate comparison between the developed model and other models in the literature, and (2) to overcome the obstacle that no contractor was willing to provide data about its cost estimates and the past bid prices of its competitors. The data of the first case study is obtained from Christodoulou (2004) and the data for the second case study is obtained from Skitmore and Pemberton (1994). Each of these sources developed their own models. Christodoulou’s data comprised historical markup percentages of competitors and Skitmore and Pemberton’s data comprised historical bid prices of competitors along with the own cost estimates of the firm providing the data for the same projects. In the first study, results from the proposed model were compared to the results of the model developed by Chrisodoulou (2004). In the second case study, the results were compared to the results of the models developed by Skitmore and Pemberton (1994) and Yuan (2011), because Yuan (2011) used the same data in his model. Using the model in these case studies helped in deducting some behavioral patterns and illustrating the effects of the different parameters on the results.

The first case study had three competitors while the second case study had 4 competitors competing against the contractor. In the first case study, the competitors were named 1, 2, and 3. 30 historical bids were available for them. Since the markups were provided directly, there was no need for the first two steps in the model. In the second case study, the competitors were named also 1, 2, 3, and 4. However, these competitors were originally named 1, 55, 134, and 221 in Yuan (2011) and Skitmore and Pemberton (1994). The number of available historical bids for each competitor was different: 33 historical bid prices were available for competitor 1, 20 for competitor 2, 12 for competitor 3, and 6 for competitor 4. The used data is included in Appendix A.

Since the available data from the literature did not include all needed information about the recency and the commonality of the historical bids, some assumptions were made to enable using the model on such data. Of course, in real-life applications, contractors would know all information and the assumptions would be minimal. The assumptions that are made in the case study are regarding the stochastic variability between the competitor's cost estimates and the contractor's own cost estimates (the σ_{ij} term), the selection of the past bids that form the likelihood function, and the selection of the Gamma parameters in cases where a competitor's past bid price is lower than the contractor's own cost estimate.

Two scenarios were simulated in each case study. The only difference between the scenarios is the number of past bids representing the "latest common bids" that are used to form the likelihood function. In scenario 1, only the last bid in the data set of each competitor is selected to create the likelihood function with. In scenario 2, we formed the likelihood function for each competitor from its latest two bids. Again, these scenarios are made just for the purpose of demonstrating the application of the model. In reality, contractors would know exactly which bids to use to form the likelihood function and which ones to use to form the preliminary distribution density functions. In each scenario, multiple values of σ_{ij} were used to see the effect of σ_{ij} on the results. The values inputted for σ_{ij} in the cases studies are put for all i and for j. In reality, contractors would have more information and they cause use a value of σ different for each i and for each j depending on their perception of cost variability between their estimation and the estimation of their competitors i in the different bids j.

In the second case study, a small number of historical bids turned out to have competitors' bid prices lower than the contractor's own cost estimates for the first three competitor. In these data points, the Gamma part of Equation 2.12 is used with proper estimation of the shape α_{ij} and rate β_{ij} parameters. Those parameters are estimated as follows: $\alpha_{1j} = 2$, $\beta_{1j} = 1.3$, $\alpha_{2j} = 3$, $\beta_{2j} = 2$, $\alpha_{3j} = 5$, $\beta_{3j} = 2$, for all values of j. The model was applied on the case studies using the R-language. The used code is provided in Appendix A.

2.6.2 Results of the First Case Study

The resulting prior distributions of the competitors (after performing the K-S test and selecting the best fitting parameters) are as follows:

- Competitor 1: Weibull distribution with scale = 10.575 and shape = 2.147.
- Competitor 2: Uniform distribution with min = 0.4 and max = 19.4.
- Competitor 3: The logspline fitting was used because it had more than one significant peeks.

Figure 2.6 shows a graphical representation of the prior distributions of all competitors.

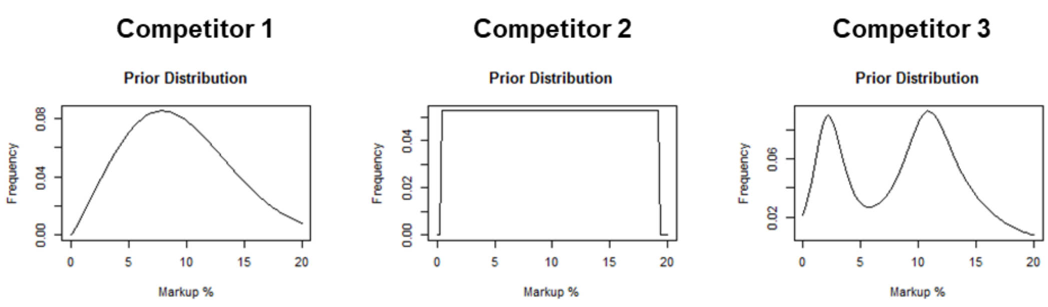


Figure 2.6. Prior Distribution of Competitors in the First Case Study.

The likelihood function and posterior distribution were calculated for each case scenario for each competitor in accordance to the steps listed in sections 2.5.5 and 2.5.6. The rest of the steps were followed to calculate the probability of winning each competitor, the proabbility of winning all competitors using Friedman and Gates' formula, the expected profit, and accordingly the optimum markup percentage.

The optimum markup percentage and its corresponding probability of winning is shown in Table 2.1 for the different scenarios and the different values of σ. Figure 2.7 shows the expected profit and probability of winning curves for all competitors in the first scnario. Figure 2.8 shows the same for the second scenario. As shown from the table and two figures, in the first scenatio, the optimum markup percentage is between 6.7 % and 7.5% with a probability of winning between 87% and 64%, depending on the value of σ. In the second scenario, the optimum markup percentage is between 6.7 % and 8.8% with a probability of winning between 60% and 55%. In bothe scenraios, there is no significant difference between the results of the Friedman's formula and the Gates' formula.

Table 2.1. Results of the First Scenario in the First Case Study.

	First Scenario							
	σ = 1%		σ = 2%		σ = 3%		σ = 4%	
	M%	P_{win}	M%	P_{win}	M%	P_{win}	M%	P_{win}
Winning against competitor 1	7.6	0.86	7.3	0.80	7.2	0.75	7.2	0.71
Winning against competitor 2	12.6	0.92	11.9	0.87	11.4	0.82	11.1	0.76
Winning against competitor 3	9.9	0.92	9.4	0.89	9.2	0.84	9.1	0.79
Winning against all competitors*	7.5	0.87	7.1	0.80	6.7	0.75	6.4	0.69
Winning against all competitors**	7.5	0.87	7.1	0.81	6.9	0.74	6.7	0.68
	Second Scenario							
	σ = 1%		σ = 2%		σ = 3%		σ = 4%	
	M%	P_{win}	M%	P_{win}	M%	P_{win}	M%	P_{win}
Winning against competitor 1	8.5	0.94	8.2	0.85	8.2	0.79	8.1	0.75
Winning against competitor 2	13	0.96	12.1	0.92	11.6	0.86	11.1	0.81
Winning against competitor 3	10.9	0.61	9.8	0.55	8.9	0.57	8.6	0.59
Winning against all competitors*	8.5	0.60	7.6	0.56	7.1	0.57	6.7	0.58
Winning against all competitors**	8.8	0.59	8.2	0.55	7.6	0.56	7.3	0.56

** Based on Friedman's formula , ** Based on Gates' formula ,*
M%: optimum markup , P_{win}: probability of winning corresponding to M%

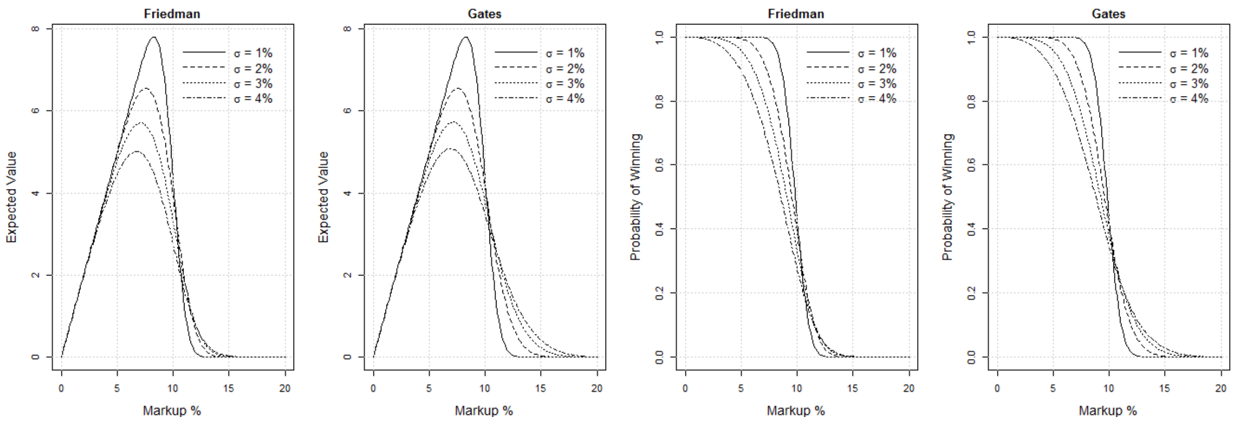


Figure 2.7. Results of the First Scenario in the First Case Study.

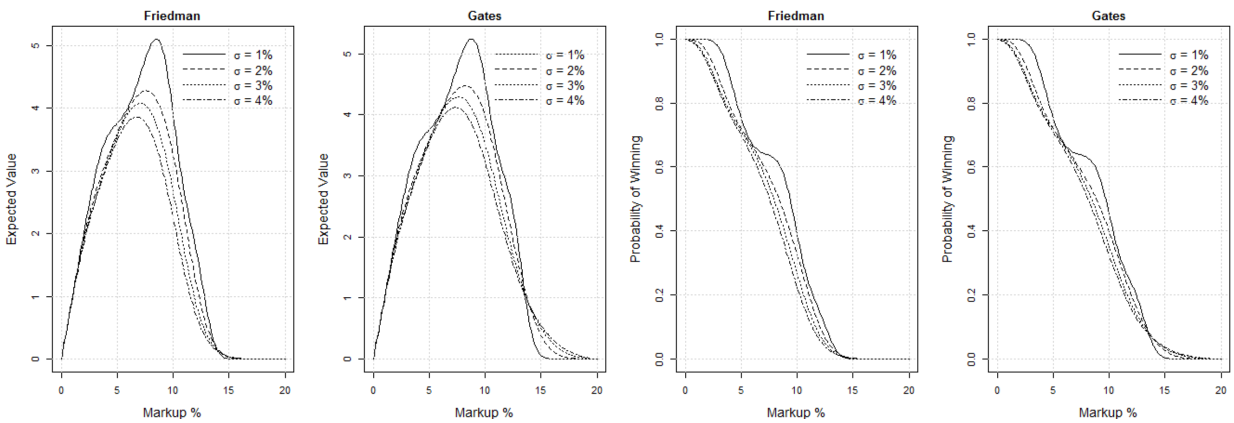


Figure 2.8. Results of the Second Scenario in the First Case Study.

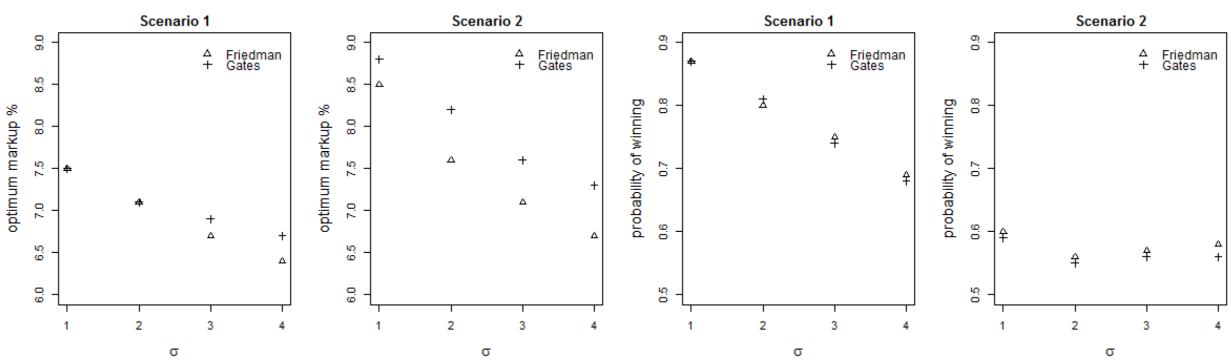


Figure 2.9. Sensitivity Analysis of How the Value of σ Affects the Results – First Case Study.

An interesting observation in the first case study is that as the variability between cost estimates (σ) increase, both the optimum markup percentages and the probability of winning increase. This is demonstrated in Figure 2.9. This means that in this case study, when the contractor has better certainty about its competitor's cost estimate (lower value of σ), it is able to enter the bid with a higher bid price and a high probability of winning.

2.6.3 Results of the Second Case Study

Since the data provided in this case study contained the competitor's bid prices, not their markups, all of the 8 steps of the model were followed. The PPDF was calculated for each competitor was calculated using Equation 2.12, followed by the MCMC sampling using the Metropolis-Hastings algorithm. The left-hand side of Figure 2.10 shows the convergence of the Markov chains and the right-hand side shows the resulting histograms of the sampled data points. The MCMC acceptance rate ranged between 77.8% and 88.1%. Since this rate is above 23.4%, it is acceptable and shows that the candidate and target functions used in the Metropolis-Hastings algorithms were suitable for one another.

The resulting prior distributions of the competitors (after performing the K-S test and selecting the best fitting parameters) are as follows:

- Competitor 2: Weibull distribution with scale = 4.22 and shape = 1.503.
- Competitor 3: The logspline fitting was used because it had more than one significant peek.
- Competitor 4: Weibull distribution with scale = 7.181 and shape = 2.106.

All historical bid prices of competitor 1 were lower than the cost estimate of the contactor for those bids. Accordingly, it was assumed that this competitor is taker with low markups. Accordingly, a Gamma distribution with shape = 3 and rate = 1.3 was selected to represent the prior distribution of that competitor. In reality, the contractor using the model can use any distribution that it believes represents the prior bidding behavior of the competitor. Figure 2.11 shows a graphical representation of the prior distributions of all competitors.

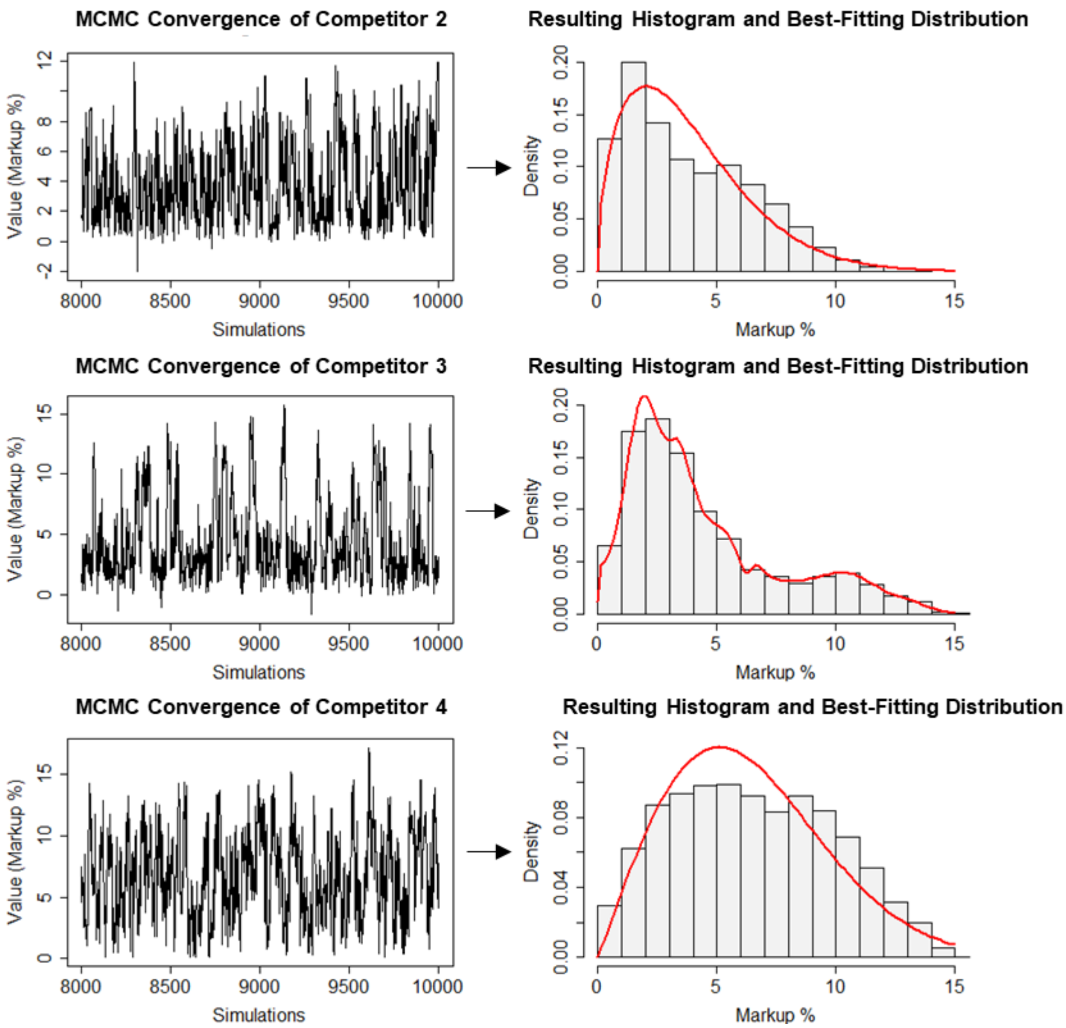


Figure 2.10. The MCMC Results of Three Competitors in the Second Case Study.

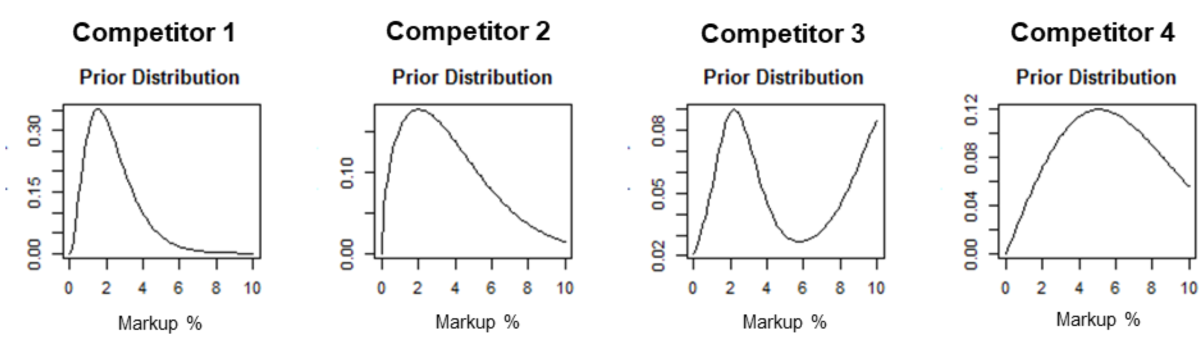


Figure 2.11. Prior Distribution of Competitors in the Second Case Study.

The likelihood function and posterior distribution were calculated for each case scenario for each competitor in accordance to the steps listed in sections 2.5.5 and 2.5.6. The rest of the steps were followed to calculate the probability of winning each competitor, the proabbility of winning all competitors using Friedman and Gates' formula, the expected profit, and accordingly the optimum markup percentage.

The optimum markup percentage and its associated winning probability in six different combinations is shown in Table 2.2 for the different scenarios and the different values of σ. For example, the first combination is for winning against bidders 1, 2, and 3 only. The combinations are made this way to enable comparison with the results of Yuan (2011) and Skitmore and Pemberton (1994) because they listed their results in the same combinations. Figure 2.12 shows the expected profit and probability of winning curves for all competitors in the first scnario. Figure 2.13 shows the same for the second scenario. As shown from the table and two figures, in the first scenatio, the optimum markup percentage is between 6.7 % and 7.5% with a probability of winning between 87% and 64%, depending on the value of σ. In the second scenario, the optimum markup percentage is between 6.7 % and 8.8% with a probability of winning between 60% and 55%. In bothe scenraios, there is no significant difference between the results of the Friedman's formula and the Gates' formula.

Similar to the first case study, in the second case study, as the variability between cost estimates (σ) increase, the optimum markup percentages increases (but not with the same strength as in the first case study). However, unlike in the first case study, in this case study an increase in σ did not lead to any significant change in the probability of winning. Also, the gap between the Friedman and Gates's formulas is significant in this case study unlike in the first case study. Discussions are made in section 2.7.

Table 2.2. Results of the First Scenario in the First Case Study.

First Scenario												
Winning the following competing bidders	Combined probability based on Friedman's equation						Combined probability based on Gates' equation					
	σ = 2		σ = 3		σ = 4		σ = 2		σ = 3		σ = 4	
	M%	P_{win}	M%	P_{win}	M%	P_{win}	M%	P_{win}	M%	P_{win}	M%	P_{win}
1 + 2 + 3	1.20	62.4%	1.24	61.4%	1.26	59.9%	1.33	59.5%	1.41	57.7%	1.46	55.7%
1 + 2	1.57	64.5%	1.55	62.5%	1.51	61.4%	1.58	64.4%	1.61	61.4%	1.62	59.3%
1 + 3	1.21	62.1%	1.29	61.4%	1.35	61.3%	1.33	59.7%	1.43	58.6%	1.5	58.2%
2 + 3	1.67	62.4%	1.81	61.0%	1.9	59.7%	1.69	61.9%	1.90	59.9%	2.12	56.4%
3 + 4	2.41	66.7%	2.55	63.4%	2.58	60.4%	2.47	65.9%	2.78	61.0%	2.9	57.1%
All	1.12	62.5%	1.17	61.5%	1.2	60.6%	1.28	58.6%	1.36	57.1%	1.41	56.1%
Second Scenario												
Winning the following competing bidders	Combined probability based on Friedman's equation						Combined probability based on Gates' equation					
	σ = 2		σ = 3		σ = 4		σ = 2		σ = 3		σ = 4	
	M%	P_{win}	M%	P_{win}	M%	P_{win}	M%	P_{win}	M%	P_{win}	M%	P_{win}
1 + 2 + 3	1.32	63.7%	1.32	62.0%	1.32	60.7%	1.45	60.7%	1.49	58.4%	1.51	55.9%
1 + 2	1.53	65.0%	1.51	63.5%	1.58	61.3%	1.56	64.3%	1.60	60.6%	1.61	58.7%
1 + 3	1.35	63.6%	1.41	62.2%	1.45	61.6%	1.47	60.1%	1.53	59.9%	1.57	59.4%
2 + 3	2.19	62.4%	2.16	60.7%	2.2	58.3%	2.32	60.4%	2.41	57.4%	2.57	53.6%
3 + 4	2.57	68.2%	2.57	63.1%	2.57	59.9%	2.72	66.4%	2.84	60.1%	2.89	56.5%
All	1.25	64.0%	1.26	62.0%	1.25	60.5	1.4	60.6%	1.44	58.2%	1.47	56.5%

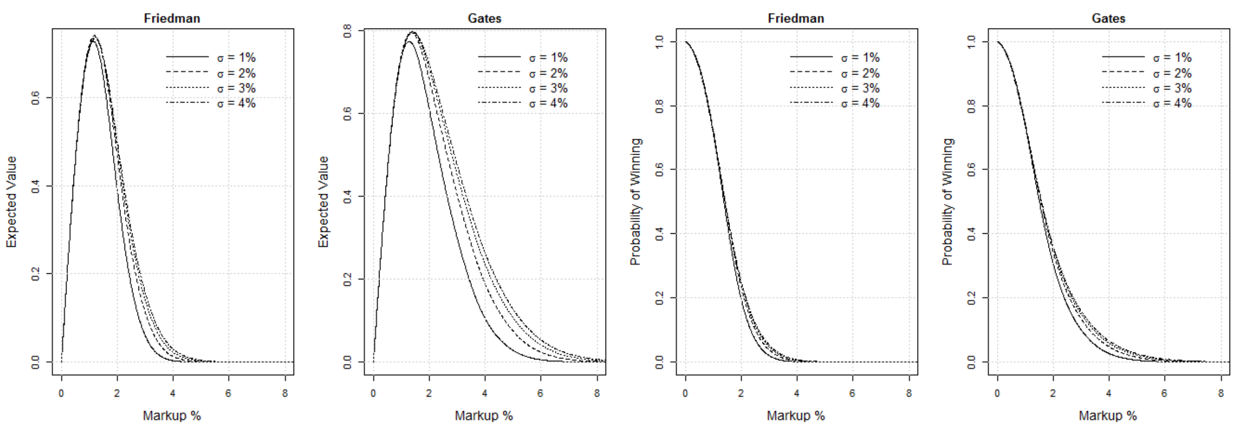


Figure 2.12. Results of the First Scenario in the Second Case Study.

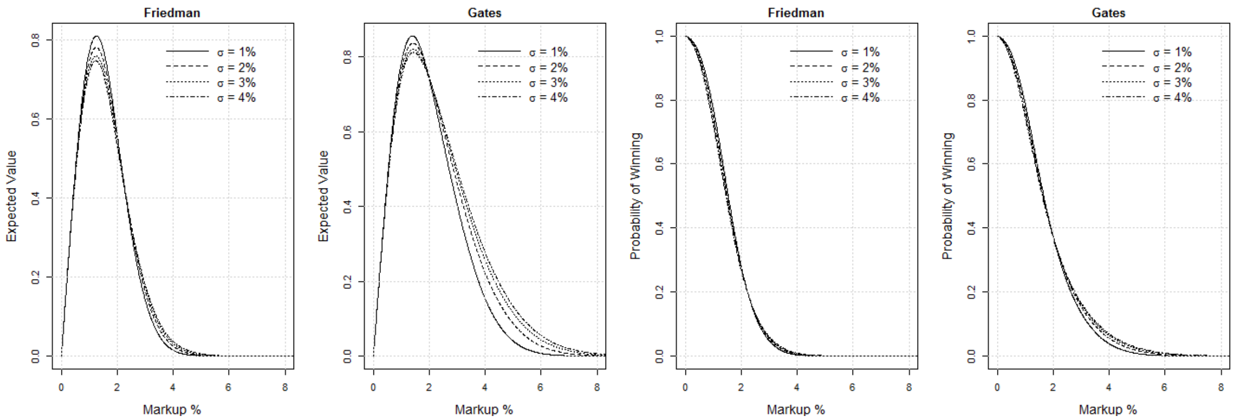


Figure 2.13. Results of the Second Scenario in the Second Case Study.

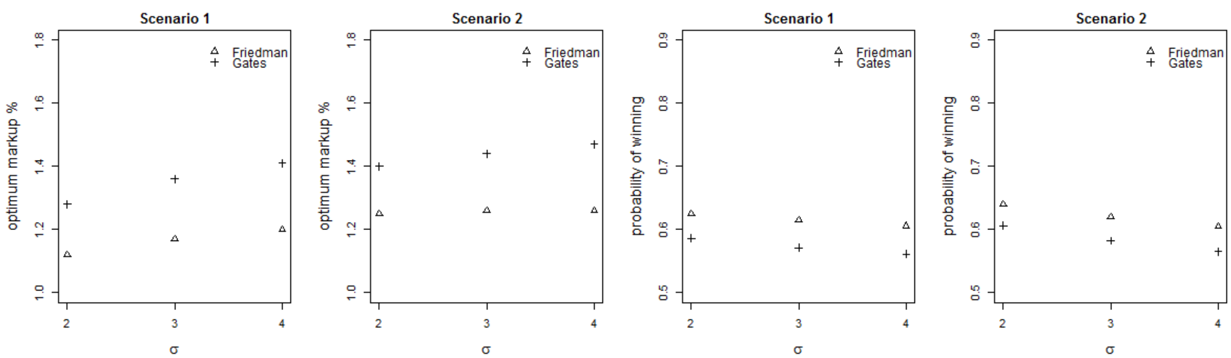


Figure 2.14. Sensitivity Analysis of How the Value of σ Affects the Results – Second Case Study.

2.7 Discussion

2.7.1 What the Two Case Studies Reveal about the Developed Model and Bidding

In the first case study, Christodoulou's model (2004) proposed 7% to be the optimal markup percentage for the data in the first case study. For the same data, our model suggested optimal markup percentages ranging from 6.4% to 8.8% depending on which value for σ is used. The probability of winning is 55% for the 8.8% markup and 87% for the 6.4% markup. The markup from Christodoulou's model lies within the range of markups suggested by our model. However, this does not mean that our proposed model is any less or more validated because both models take entirely different methodological approach. However, such closeness in results still is meaningful in the sense that it shows that the optimal markup is reasonable and sensible.

For the second case study, our model was compared to those of Yuan (2011) and Skitmore and Pemberton (1994). The comparison is shown in Table 2.3. It can be noticed from the table that there is a significant difference between the markup percentages proposed by Skitmore and Pemberton (1994) and those by Yuan (2011); where those by Skitmore and Pemberton (1994) are significantly larger than those by Yuan (2011). Despite that both models utilize correlation analysis for coming up with the markup percentages, the significant difference is resulting from their different methods of calculating the expected profit. Our model, as well as the model by Yuan (2011) suggest a lower markup is more suitable to win the projects. Since their results are close to one another, they somehow cross-validate each other. When the model by Skitmore and Pemberton (1994) was further investigated to see what causes such a significant difference, it was concluded that their model augments the cost estimation error while calculating the expected profit. The proposed model has an advantage over the other two models because it incorporates dynamic behaviors and incomplete information of competitors.

Table 2.3. Second Case Study – Comparison with Other Models in the Literature.

Competing bidders	Skitmore and Pemberton (1994)	Yuan (2011)	Proposed Model*
1 + 2 + 3	13.47 %	2.79 %	1.20% to 1.51%
1 + 2	10.98 %	3.69 %	1.51% to 1.62%
1 + 3	12.06 %	3.74 %	1.21% to 1.57%
2 + 3	7.70 %	3.29 %	1.67% to 2.57%
3 + 4	6.62 %	--	2.41% to 2.90%

* *Depending on the scenario and the value of σ*

The markup percentages of the developed model are the lowest among the three models because the model assumed that competitor 1 is a risk taker with low values of markup in previous bids where his missing or non-reasonable data points were replaced with low markup probability density functions. That is why, in order to win against him, the contractor would bud with a very low markup percentage. In reality, assumptions would be minimal, or at least would be better informed. The purpose of making assumptions here is to make use of the model and demonstrate it. The assumptions were only made to substitute for the missing conditions of the bidding environment. The difference between the optimal markup percentages resulting from the proposed model and those from Yuan's model is mainly due to two primary factors. The first factor is that both models utilize completely different methodologies. The second factor is that the proposed model is more dependent on recent historical; giving them slightly higher weights than older ones; unlike Yuan's model. It happens that in this case study, the recent bids of competitors are much lower than the older ones. This resulted in the model considering the competitors as attaining dynamic behavior; changing their markup behavior from higher percentages to lower percentages. As such, the model forecasted that their future bid prices would tend to have low markup percentages; that is why it proposed a low optimal markup to increase the probability of winning.

To benefit from the full potential of proposed model, the contractor using it must have additional information other than just historical bid prices of competitors. It is acceptable to have incomplete information about the historical bid prices of some competitors. However, at least the contract must have a general idea of the behavior of its competitors to be able to replace the missing data with well-informed educated beliefs. Also, the contractor should be the one to determine which historical bids are to be considered old (to be used in forming the preliminary distribution density function) and which ones are to be considered the latest common bids forming the likelihood function. Because such information was not present in the literature, they were assumed, and the scenarios were made accordingly.

A pattern that was noticed is that the probability of winning increases when σ (the variability, or belief of variability, between the contractor's estimate and the competitors' cost estimate) decrease. This is beneficial in the sense that if a contractor is highly certain that his cost estimate is within a small range from the competitors' cost estimate, the model would yield higher optimal markup percentages for the new bid while maintaining the same probability of winning. A conclusion can be made here is that a higher accuracy of cost estimation increases the chance of winning project, and plays a major role in setting the markup for the future projects. This aligns with the theoretical discussion provided by Capen et al. (1971). With regards to the optimal markup, each case study had a different behavior when it came to the effect of σ on the optimal markup. In one case study, lower resulted in higher markup percentage. In another case study, the change in σ did not yield to any significant change in the markup percentage. As such, the effect of σ on the optimal markup is dependent on the case; not generalized. In the case studies, the difference between the optimal markup percentages corresponding to the different values of σ was not significant; which suggests that the optimum markup is not very sensitive to σ. Finally, it should be clarified that even the highest probability of winning does not guarantee winning. No bidding in the world guarantees winning. Models just provide analysis that increases the chances of winning.

2.8 Outcomes and How They Relate to Dispute Mitigation

The developed model will enable more accurate bid price determination through its unique integration between Bayesian statistics and decision theory. Also, unlike previous models, it will enable contractors to produce sound bid price estimates in cases of incomplete information about their competitor's past bids and in cases where the competitors attain dynamic bidding behavior. This should be beneficial to contractors as it will help them in developing stable bids that balance between the probability of winning and the expected profit. By doing so, contractors who are awarded projects will not attain claim-oriented behavior to recover losses resulting from bidding too low since their bid price is balanced. As such, this module will partake in creating a healthy contracting environment and preventing disputes arising from unbalanced bids. Finally, construction stakeholders would benefit from this research as it will help them in better understanding the bidding decision-making processes, and consequently involve in healthier contracting environments.

2.9 Recommendations for Future Work (Further Development and Validation)

Validating models of this nature on real projects has not been attempted before. The only validation these models go through are theoretical validations (making sure the statistical concepts hold). The norm in such situations is that after one makes sure that his/her model is logical and statistically correct, he/she uses it in hypothetical case studies or historical case studies and compares its resulting bid prices to the ones resulting from other models. Examples include Hosny and Elhakeem (2012), Yuan (2011), and Christodoulou (2004). However, making comparisons between the resulting bid prices of models is not informative enough. The question here is, so what? Having an optimum bid price that is lower or higher than that of another model does not provide any measure of evaluating how good the models are since the bid price it is not an objective function. The objective function is maximizing the number of awarded projects.

There are two possible ways for truly validating and evaluating the effectiveness of any bidding model. The first way is to have real bidding data of a contractor's cost estimates and its competitors' historical bid prices and let the contractor use the model to produce bid prices for future projects, then evaluate the percentages of projects that he won before and after using the model. A problem with this approach is that it is almost impossible to convince contractors to provide the needed data. Another problem is that even if a contractor provided this data, the model's efficiency can only be evaluated after tens and may be hundreds of entered bids; which is time consuming. As such, a second way is proposed to evaluate and validate the bidding models; which is by using simulation – especially agent-based modeling (ABM). To further explain, the ABM model would simulate several contractors in an area; where each contractor uses a different bidding model from the literature. Some contractors would not use any models and just enter bids with random markup percentages. Then a series of bids (let's say 300 bids) are made. These series are then run for thousands of times. Finally, the percentages of bids won by each contractor is calculated. This will enable us to compare between the efficiency of bidding models in general vs. just randomly selecting markup percentages. It will also enable comparing between the different bidding models and guide the way on which direction should the bidding research follow.

One additional recommendation is to program a user-friendly software that uses the developed bidding model and does its required calculations without letting the users get into the details of the mathematical formulations. The developed model tells the user which markup percentage to use to win the project. The software is recommended to incorporate the model of Ahmed et al. (2015) as well. The model of Ahmed et al. (2015) informs the users whether their bid price makes them prone to the winner’s curse or not; but it does not inform them on which optimum bid price to use. It just provides the lower limit. As such the proposed software should compare between the results of the developed bidding model with the ones by Ahmed et al. (2015). The bidder should use a bid price that is the larger of those outputted by the developed model and the model of Ahmed et al. (2015).

2.10 Related Appendices

Appendix A presents the R code for the developed bidding model and its use in the two case studies. It also presents the bidding data of the case studies as supplied from their original sources.

CHAPTER 3:
BEST PRACTICES FOR AVOIDING AND MITIGATING OUT-OF-SEQUECE (OOS) WORK

3.1 Overview

In the U.S., it is estimated that the productivity of the construction industry has been dropping at an average rate of 0.5% per year since the 1960s. In fact, the percentage of productive work in a typical construction project ranges between 30-40%, resulting in failure to deliver approximately 50% of the projects on time and on budget (Hanna, 2010). Hanna's data is also matched up by Horman and Kenley (2005). Horman and Kenley (2005) conducted a meta-analysis of 24 published studies on building projects over the past 30 years, and reported that 49.6% of operational time was wasted without adding value in their case projects. Such statistics have led to notable interest from research institutions, academics, and industry practitioners seeking root causes for the industry's substantial productivity problems.

There are many causes for poor labor productivity; including but not limited to, change of scope in terms of frequency and size, poor scheduling practices, poor coordination between trades, unavailability of skilled labor, schedule pressure techniques such as overmanning, rework, slow flow of information between different parties, and out-of-sequence work. Many of these inefficiencies have been addressed by researchers and construction professionals. For example, among several other studies, Hanna et al. (2007) investigated how *overmanning* negatively impacts productivity, Thomas (2000) studied the correlation between *labor hours* and productivity, and Ibbs (2012) quantified the impact of *the magnitude of change* on productivity. However, no works have been found that study the impacts of OOS work on productivity, cost, or even schedule, despite the fact that OOS work has been reported to be one of the significant factors contributing to construction inefficiencies and loss of labor productivity (Thomas et al. 1992; Halligan et al., 1994; Thomas and Napolita, 1995; Hanna et al., 1999; Hanna et al., 2002; Thomas et al., 2003; Klanak and Nelson, 2004; Hanna, 2006; Thomas and Horman, 2006; and Dai and Maloney, 2009).

Moreover, all factors impacting productivity have been studied in terms of what causes these factors and how to prevent them from happening, except for out-of-sequence work. For example, Ye et al. (2015) investigated the causes of *rework* in construction projects, and Arian et al. (2006) identified the causes of *inconsistencies* between design and construction in projects. However, there is no literature solely devoted to studying OOS work in terms of its root causes, triggers, impacts, and alleviative and preventive practices.

Suhail (1993) defines OOS work, also referred to by him out-of-logic work, as *"the progress of an activity that starts or finishes contrary to the predefined relationship with its predecessors"*. Another definition is made by Waagner (2012), where *"out-of-sequence is when work begins on an activity prior to the completion of its predecessor activities"*. Waagner's definition assumes the activities have a finish-to-start relationship without any lag or lead time. Through combining the most impactful concepts of both definitions, Research Team 334 of the Construction Industry Institute (CII) defines OOS work as "*an activity or series of activities that were not performed according to baseline planned logical sequencing*".

The current literature does not address OOS work independently, but rather discuss it as a secondary factor. However, the resulting statistics indicate that OOS work is a major problem that should be studied as a primary cause of schedule overruns, cost overruns, quality decline, and productivity decline. As such, there is a need for studies that look into OOS work in depth to determine its causes and develop practices to prevent it or at least mitigate its impacts.

3.2 Objective

The objective of this module is to identify the causes and early warning signs of OOS work and their characteristics, as well as the best practices to avoid and mitigate its impacts.

The objective could be divided into the following sub-objectives:

- Recognize the extent of OOS work in the construction industry;
- Identify the causes of OOS work and quantify their characteristics (likelihood occurrence an impacts);
- Identify the early warning signs of OOS work and investigate its relationship with the occurrence of OOS events;

- Investigate the impacts of OOS work on project performance in terms of productivity, schedule, cost, quality, and safety;
- Create a scoring system that measures a project's proneness to OOS work;
- Investigate the difference between owners and contractors in terms of their perception of the frequency and impacts of the factors that cause OOS work;
- Develop recommended practices to avoid and mitigate OOS work, and
- Develop a user-friendly tool that aids stakeholders in assessing their project' proneness to OOS work and how to avoid and mitigate OOS events in their projects.

3.3 Background Information about OOS Work

3.3.1 OOS as one of the main causes of labor productivity problems:

Thomas et al. (1992) collected productivity data from construction projects in 11 different countries and conducted statistical analysis on them. They found that the average daily productivity for the nondisrupted days was 0.042 work hr/sq ft, while disrupted days had an average productivity of 0.205 work hr/sq ft, which is 388% higher. Out-of-sequence work was found to be one of the top factors contributing to the drop in labor productivity, along with rework and material storage and availability problems. Statistically speaking, the disrupted days caused by out-of-sequence work were on average 17.6% of the total disrupted days of the projects – excluding disruptions due to weather conditions. Several other studies have reported that OOS work is one of the significant factors contributing to construction inefficiencies and loss of labor productivity (Halligan et al., 1994; Thomas and Napolita, 1995; Hanna et al., 1999; Hanna et al., 2002; Thomas et al., 2003; Klanak and Nelson, 2004; Hanna, 2006; Thomas and Horman, 2006; and Dai and Maloney, 2009). Drops of productivity due to OOS work, either caused by contractors, designers, owners or third parties, lead to "Loss of productivity claims"; which always pose unique challenges (Kallo, 1996; Klanak and Nelson, 2004). In many of these cases, it is difficult to separate the cause of productivity drop and the parties focus on the claims instead of focusing on the project's welfare. Out-of-sequence also causes higher cost premiums (Horman et al., 2006). Moreover, out-of-sequence in an activity may generate less value than planned for, increase fatigue, weaken morale, surge space congestion, and damage interdependency with other activities (Han et al., 2012).

3.3.2 Schedule pressure as a trigger for OOS:

Nepal et al. (2006) discussed the effects of schedule pressure on construction performance. Schedule pressure is when project managers intend to accelerate the project by aggressively minimizing the planned durations of the scheduled activities. Accordingly, workers experience work pressure because they perceive that the available time allocated to activities is insufficient, yet the deadlines are obligatory. One of the negative results of such pressure is that the workers would perform their work out of sequence. As schedule pressure increases, the amount of OOS work increases, leading to an increasing amount of rework as demonstrated in the causal loop diagram in Figure 3.1. Such statement is supported by a survey conducted by Nepal et al. (2006) on 194 practitioners from 38 different projects. However, the main focus of their research was the effects of schedule pressure, not out-of-sequence work, on construction projects.

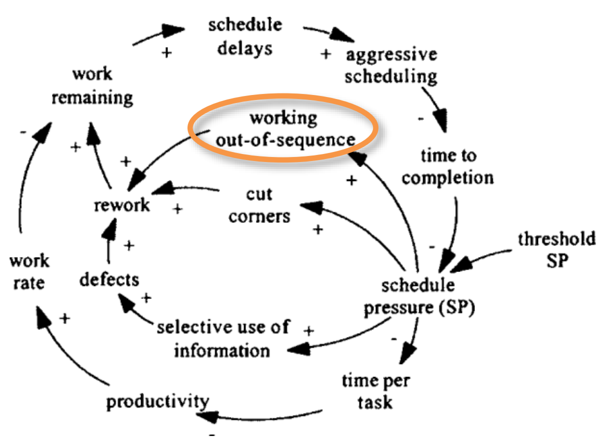


Figure 3.1. Dynamics of schedule pressure (Source: Nepal et al., 2006)

3.3.3 OOS from a site material management point of view:

Collectively, there is around 40% reduction in daily productivity resulting from material management deficiencies (Thomas and Smith, 1992). From a site material management point of view, OOS work is one of the most contributing factors of material management deficiencies

(Thomas et al., 2005). A case study examined by Thomas et al. (2005) indicated that vendors' delivery rates that are not compatible with the installation rate in the field, hence named out-of-sequence delivery, cause OOS work and disruptive interferences on site. The findings of the case study are backed by data from more than 125 projects from six continents over a span of 25 years of data collection by H. Randolph Thomas. Accordingly, project managers should plan with vendors delivery rates that are compatible with the installation rates.

3.3.4 OOS from a Critical Path Method (CPM) Scheduling View:

From a CPM scheduling view, Harris (1978) defined a group of factors on which activities' sequencing is based, including physical dependency, hard and soft logic, safety considerations, trade interactions, resource limitation, and personal preference. Furthermore, Echeverry et al. (1991) reiterated Harris' factors and cited path inferences, codes, and regulations as additional factors. Most schedulers nowadays use one of two primary means to deal with out-of-sequence activities. These means are commonly known as “Retained Logic” and “Progress Override” (Waagner, 2012). These two means are mainly for the scheduling software to be able to handle out-of-sequence. The “Progress Override” mode treats the OOS activity as if it has no predecessors so it can continue without being affected by its incomplete predecessors. So, if it had a start-to-finish relationship with its predecessor, the scheduling software would break that relationship and assumes no predecessors and ignores the initial logic. The “Retained Logic” mode allows the out-of-sequence activity to start earlier than the finish of its predecessor, but schedules its completion in accordance with the network logic. The activity will not be allowed to complete until all its predecessors are completed, and the original duration is satisfied. Most of the times, both modes produce non-realistic results in the project report and the weekly updates as they result in drastic change the schedule logic, especially when used without rigorous supervision by senior decision makers. In fact, sometimes some OOS activities do not have negative impacts on the project, but the way schedulers handle them in the software and periodic reports give false indication of augmented impacts. Such false indications may lead project managers to take faulty measures that would, themselves, significantly impact the project.

3.3.5 OOS Work and Safety:

Not only do OOS activities cause negative impacts to project cost and duration, they also have negative impacts on safety (Mitropoulos and Memarian, 2012). In 2013, the construction industry had 18.1% of the total fatal work injuries in the US, summing up to 828 fatalities in 2013 alone (Bureau of Labor Statistics, 2013). The multiple and concurrent tasks normally present in projects require effective coordination and collaboration between the members of a crew and between the different crews. Even with most skilled crews, safety risks still exist. In cases of out-of-sequence work, the communication level decreases and the updated work plans may not reach all crews, thus significantly increasing safety risks on site. Moreover, in repetitive activities, workers exercise less cognitive attention by time, so they are not prepared for unplanned interfering activities. At this setting, the occurrence of an out-of-sequence activity degrades the safety of the project.

3.4 Methodology

A multi-step methodology is utilized to tackle the objective of this module as shown in Figure 3.2. The first five steps are discussed in the "Methodology" section (section 3.4) and the last step is discussed in the "Results and Analysis" section (section 3.5).

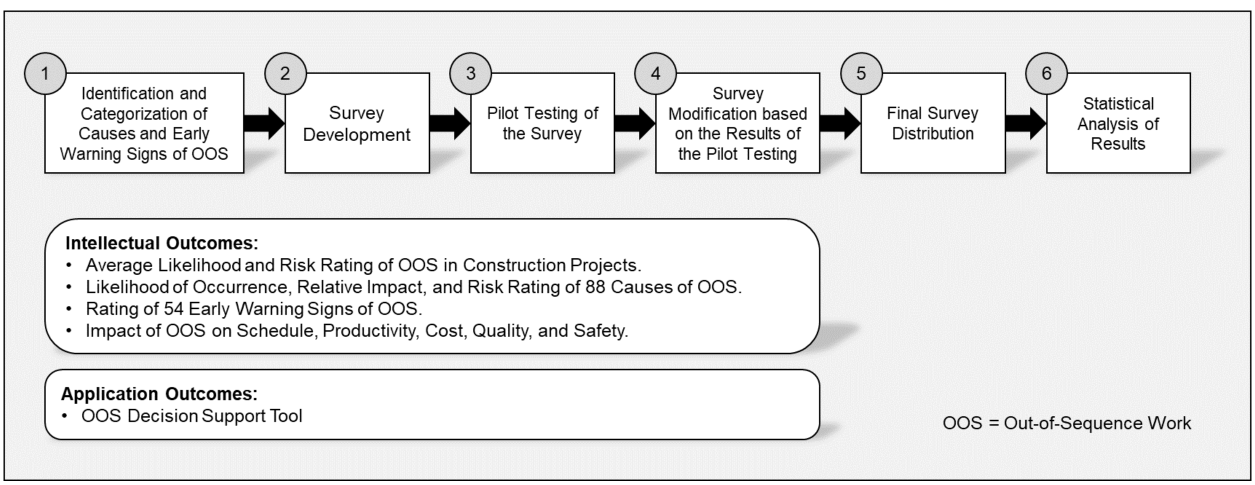


Figure 3.2. Research Methodology and Outcomes of Chapter 3

A panel of 13 industry professionals was established at the beginning of the research. Of the panel members, six professionals represented owner companies and seven represented contractor companies; which is a reasonable balance that provides broad views. This industry panel has actively participated throughout the duration and steps of the research via periodic meetings and conference calls. This ensured that the findings of the research are highly practical and beneficial to the industry. This approach has been used by the Construction Industry Institute (CII) in almost all of its applied research projects and has been proven to produce robust and valid outcomes. The following sub-sections provide detailed description of the methodology.

3.4.1 Step 1: Identification of Causes and Early Warning Signs of OOS

Throughout several meetings and online workshops with the industry panel, as well as comprehensive review of the literature, the author has: (1) identified 88 causes of OOS; (2) identified 54 early warning signs of OOS, and (3) categorized the causes and early warning signs of OOS into 11 categories. An important distinction is made between causes and early warning signs of OOS. Causes of OOS are factors or events that directly cause OOS work. On the other hand, early warning signs are factors or events that are just correlated with OOS without a direct relationship. For example, late delivery from vendors is a direct cause of OOS. But, having lower wages relative to close-by projects in the surrounding area is considered an early warning sign rather than a direct cause because it does not mean that workers will automatically leave the project and go work for the close-by project, thus leading to OOS. The identified causes of OOS, early warning signs of OOS, and their categories are discussed in more details in Section 3.5.

3.4.2 Step 2: Survey Development

After identifying the causes and early warning signs of OOS, an expert-based survey was developed to:

- Determine the likelihood of occurrence (L) and relative impact (I) of OOS work on construction projects in general;
- Determine the likelihood of occurrence (L), relative impact (I), and risk rating (RR) of each of the causes of OOS;

- Determine the rating of the early warning signs of OOS (how strong are the early warning signs correlated to OOS), and
- Recognize the general impact of OOS work on schedule, productivity, cost, safety, and quality.

To ensure reliable results, it was essential that the used Likert scale be well-defined to the respondents so that they would all have the same understanding of the meaning of the different scale numbers. This also minimizes qualitative bias by the respondents. That is why the standard Likert scale that is developed by the CII in the International Project Risk Assessment Implementation Resource was used (CII IR 181-2). The following bullets show the different values of the likelihood of occurrence (L) and their corresponding quantitative meaning:

- NA = Not applicable to this project
- 1 = Very low probability and occurs in only exceptional circumstances (<10% chance)
- 2 = Low chance and unlikely to occur in most circumstances (10% chance <35%)
- 3 = Medium chance and will occur in most circumstances (35% chance <65%)
- 4 = High chance and will probably occur in most circumstances (65% chance <90%)
- 5 = Very high chance and almost certain and expected to occur (90% or greater chance of occurrence)

The following bullets show the different values of the relative impact (I) and their corresponding quantitative meaning:

- 1 = A = Negligible and routine procedures sufficient to deal with the consequences (<5% increase in cost or time)
- 2 = B = Minor and would threaten an element of the function (5-10% increase in cost or time)
- 3 = C = Moderate and would necessitate significant adjustment to the overall function (10-20% increase in cost or time)
- 4 = D = Significant and would threaten goals and objectives; requires close management (20-50% increase in cost or time)

- 5 = E =Extreme and would stop achievement of functional goals and objectives (>50% increase in cost or time)

The risk rating (RR) is a value calculated for each cause of OOS based on its likelihood of occurrence (L) and relative impact (I). This value is not inputted directly by the respondents, but rather calculated using Equation 3.1 for each cause of OOS. Each respondent r, inputs the likelihood of occurrence L_{ri} and relative impact I_{ri} for each cause of OOS i. The relative impact for each cause I_{ri} for each respondent is calculated by simply multiplying the corresponding L_{ri} and I_{ri} that are inputted by the respondent. The final risk rating of each of each cause RR_i is the summation of all the relative impacts of correspondents for that same cause as shown in Equation 3.1; where N_i is the number of responses in OOS cause i.

$$RR_i = \frac{1}{N_i} \sum_r L_{ri} \times I_{ri} \qquad \text{Eq. (3.1)}$$

3.4.3 Step 3: Pilot-Testing of the Survey

Although the developed expert-based survey was reviewed thoroughly by the author, the research collaborators, and the industry panel, it was pilot-tested to ensure maximum benefits and eliminate any mistakes. The survey distribution of the pilot-testing was administered by the industry panel members. Thus, no IRBs were required from the University of Tennessee. Respondents of the pilot study were asked at the end of the survey to provide their comments on the survey in terms of OOS causes or early warning signs that need to be added/modified/deleted, questions that need to be added/modified/deleted, clarifications that need to be made to ensure consistency of understanding, and any other suggestions to make the survey more beneficial. The pilot survey was completed by 29 industry professionals.

3.4.4 Step 4: Survey Modification based on the Results of the Pilot Testing

Comments from the respondents in the pilot-testing were recorded and the survey was fine-tuned accordingly. The pilot-testing enabled removing of some duplications and enhancements of several items. But nothing major was changed. In this stage as well, the survey was transformed from being an electronic PDF form into an online survey for better ease of use and accessibility.

3.4.5 Step 5: Distribution of the Expert-Based Survey

The final form of the survey was sent to professionals across the US. Overall, the survey was sent to 281 construction professionals. Of those, 106 completed the survey but 16 of them provided incomplete and insufficient responses. As such, 88 responses were included in the analysis. The final survey was administered by the CII. Thus, no IRBs were required at the University of Tennessee. *The questions used in the final survey are listed in* ***Appendix B***.

3.4.6 Step 6: Statistical Analysis of Results

Details of this step are stated in Section 3.5.

3.5 Results and Analysis

3.5.1 Respondent Data

The total number of expert respondents with complete responses is 88. This number is considered acceptable, specially that the survey takes an average of one and a half hours. Moreover, Section 3.6 further discusses the sufficiency of the sample size using statistical methods to ensure that the obtained data from the 88 experts are reliable and representative of the industry.

The respondents represented all of the central parties to any construction project as they were holding technical and managerial positions in owner, engineering, contractor, MEP, and supplier companies. One third of the respondents represented owners and another third represented contractors. 16% of the respondents represented engineering firms, 9% represented MEP trades, and only 3% represented supplier firms as shown in Figure 3.3.

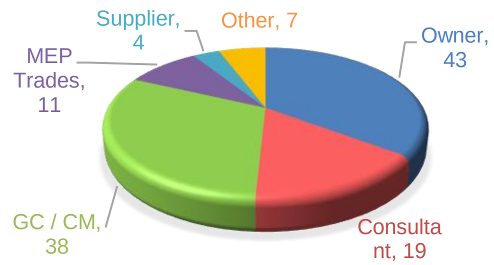


Figure 3.3. Count of the Expert Respondents and their Categories.

The average experience of the respondents is 25.1 years, while the collective experience is of all respondents is 2,213 years. Sixty percent of the respondents had more than 20 years of experience, and 85% had more than 10 years of experience; which means that their responses are based on wide experience that provide reliable and well-rounded answers that could be could be considered representative of the construction industry in the US.

As for the geographic distribution, the majority of the respondents (80%) were located in the US and distributed across 16 states mainly in the Midwestern, Southern, and North-Eastern USA. Others were located in Canada (4.5%), Columbia (4.5%), the UK (2.3%), Ireland (1.1%), India (1.1%), Malaysia (1.1%), and South Africa (1.1%). The responses of the respondents from foreign countries were not different from those in the US. So, they were included in the analysis.

3.5.2 Out-of-Sequence Work in Construction Projects in General

The respondents were asked to rate the likelihood of occurrence and relative impact of OOS in general. The intent of this question was to investigate how big of a problem is OOS in the construction industry by determining how often it takes place and how strong it impacts construction projects. The results were significant as shown in Table 3.1. The mean frequency of OOS is between the medium (value of 3) and high (value of 4). Given the defined values of the Likert scale in the methodology section, this means that the respondents encountered OOS in around 64% of their projects; which is a significant number indicating how often OOS takes place. It should also be noted that 50% of the respondents stated that they encounter OOS in a high (value of 4) to very high (value of 5) rate of occurrence. It can also be seen that the mean impact of OOS is between moderate (value of 3) to significant (value of 4). This value of 3.44 corresponds to an added average of 24% to project cost and/or time as an impact of OOS. Moreover, 52% of the respondents stated that OOS is a problem that has significant to extreme impacts to projects. This is also a significant number highlighting the magnitude of the negative impacts of OOS. This is the first research effort to determine such statistics as it is the first one to be focused mainly on OOS work. These statistics provide strong points of departure and alerts for researchers and practitioners to direct their focus towards investigating OOS in more depth.

Table 3.1. Out-of-Sequence in Construction Projects.

Questions	Respondents' Answers	
	Mean Rating (from 1 to 5)	Standard Deviation
How frequently do you typically encounter OOS in your projects?	3.52	0.92
How would you rate the negative impacts of out-of-sequence (OOS) work in construction projects?	3.44	0.83

The respondents were asked to rate the likelihood of occurrence and relative impact of OOS in different project types; namely industrial, infrastructure, building, and renovation/revamp. This categorization followed the standard CII project categorization at the time of the study. For example, the industrial category includes projects such as oil/gas production facilities, power plants, and mills. The infrastructure category includes projects such as airport runways, highways, and rails. The building category includes projects such as hotels, schools, hospital, and residential buildings. The renovation/revamp category includes projects such as retrofitting, modernization, and repair. The respondents were informed to answer with respect to the project types that they are experienced at. For example, if a respondent is not experienced in infrastructure projects, he/she would leave the corresponding question part blank. The results are shown in Table 3.2, where the mean rating ranges from 1 to 5 and follows the Likert scale definitions in Section 3.4.2.

Table 3.2. Out-of-Sequence in Different Types of Construction Projects.

Questions	Project Type	Respondents' Answers	
		Mean Rating	Std. Dev.
Rate the frequency of OOS for the following project types	Industrial	3.56	1.03
	Infrastructure	3.33	1.24
	Building	2.70	1.10
	Renovation/Revamp	3.83	0.78
Rate the impacts of OOS in the following project types	Industrial	3.57	0.74
	Infrastructure	2.96	1.09
	Building	3.04	0.96
	Renovation/Revamp	3.58	0.96

From Table 3.2, it is observed that renovation/revamp projects encounter OOS work more than the rest of the project types. Also, OOS is more impactful on renovation/revamp projects more than the other project types. This is logical because renovation/revamp projects encounter are complex, fast-paced, and require simultaneous interdisciplinary trades. After renovation/revamp projects come industrial projects in terms of susceptibility to OOS work and its corresponding impacts. Although OOS occurs in infrastructure projects more than it does in building projects, it has less impacts on infrastructure projects than it does in infrastructure projects. The categories of projects shown in Table 3.2 are defined in Figure 3.4. The expert respondents were shown such definitions prior to answering the questions in Table 3.2 to avoid any misunderstanding or misclassification of project types.

Project Types:

Industrial Projects

Capital projects that provides an output in terms of assemblies, sub-assemblies, chemical compounds, electricity, food, or other marketable goods. Industrial projects are primarily designed by chemical, mechanical, or electrical engineers, and may be considered "light" or "heavy" industrial based on the amount of process steps/equipment included in the project. Examples include the following:

- oil/gas production facilities
- textile mills
- chemical plants
- pharmaceutical plants
- paper mills
- steel/aluminum mills
- power plants
- manufacturing facilities
- food processing plants
- refineries
- civil/industrial infrastructure
- plant upgrade/retrofit

Infrastructure Projects

Capital project that provides transportation, distribution or facilities supporting commerce or interaction of goods, service, or people. Infrastructure projects generally impact multiple jurisdictions, stakeholder groups or a wide area. Examples include the following:

- airport runways
- electrical distribution/transmission
- pipelines/pumping stations
- flood control facilities
- highways
- dams or levees
- marine or air terminals
- navigation locks
- canals
- rails
- tunnels
- water/wastewater/solid waste processing
- telecommunication or other wide area networks.

Building Projects

Capital projects that provides an output in terms of space for living, working, or interacting. Building projects are primarily designed by architects and may be single or multiple stories in height. Examples include the following:

- Offices
- Schools (classrooms)
- Banks
- Research and laboratory facilities
- Medical facilities
- Nursing homes
- Institutional buildings
- Stores and shopping centers
- Dormitories
- Apartments
- Hotels and motels
- Parking structures
- Warehouses
- Light assembly and manufacturing
- Churches
- Airport terminals
- Recreational and athletic facilities
- Public assembly and performance halls
- Industrial control buildings
- Government facilities

Renovation/Revamp Projects

or work of replacing, restoring, repairing, or improving this facility with capital funds or non-capital funds. It may include additional structures and systems to achieve a more functional, serviceable, or desirable condition, including improvement in the following respects:

- profitability
- reliability
- efficiency
- retrofit
- reconstruction
- shutdown/turnaround/outage
- maintenance project (not including routine maintenance actions)
- modernization
- improvement project
- repair project (not including routine maintenance actions)
- safety
- security
- environmental performance,
- alteration
- rehabilitation
- de-bottlenecking project
- refurbishment
- modification
- upgrade
- makeover
- rebuild
- overhaul
- replacement
- or compliance with regulatory requirements.
- betterment
- reclamation
- regeneration
- redevelopment
- relocation
- reutilization
- restoration.

Figure 3.4. Categorization of the Project Types that are Used in the Survey

3.5.3 Causes of Out-of-Sequence Work

The number of identified causes of OOS work is 88. The expert respondents were shown the 88 causes of OOS and were asked to rate the following for each of those causes:

1. The likelihood of occurrence (L) – how likely or how often does the OOS cause take place in average, and

2. The relative impact (I) – the expected impact on the project in case the OOS cause took place.

The 88 causes of OOS are categorized under the following 11 categories:

A. Project Team (9 Causes)
B. Planning (12 Causes)
C. Engineering (8 Causes)
D. Execution (21 Causes)
E. Material Management (8 Causes)
F. Quality Management (5 Causes)
G. Safety Management (3 Causes)
H. Resource Management (8 Causes)
I. Change Management (5 Causes)
J. Commissioning (3 Causes)
K. Legal/Commercial Aspects (6 Causes)

Table 3.3 shows the different causes of OOS along with their likelihood of occurrence (L), and relative impact (I), based on the replies of the expert respondents. It also shows the and risk rating (RR) of each OOS cause based on Equation 3.1.

Table 3.3. The Causes of OOS Work and their Corresponding Likelihood of Occurrence, Relative Impact, and Risk Rating

Causes of Out-of-Sequence Work			Likelihood of Occurrence (L)		Relative Impact (RI)		Risk Rating (RR)	
Category	Description		Mean (1-5)	Std. Dev.	Mean (1-5)	Std. Dev.	Mean (1-25)	Std. Dev.
A. Project Team	A1	Lack of team alignment	2.99	1.05	3.24	0.87	10.35	5.31
	A2	Leadership deficiency	2.89	1.03	3.28	0.93	10.00	5.35
	A3	Project chain of command not properly established/followed	2.64	1.12	3.00	1.03	8.62	5.64
	A4	Poor communication between different project parties throughout the project	3.43	0.95	3.69	0.85	12.99	5.60
	A5	Inappropriate team size	2.43	0.99	2.73	0.96	7.19	4.52
	A6	Not enough attention to periodical meetings	2.29	0.99	2.49	0.87	6.30	4.39
	A7	Lack of project team experience relative to type and size of project	3.09	1.06	3.43	0.95	11.07	5.87
	A8	Social and political influences within the project team	2.09	1.20	2.34	1.11	6.11	6.15
	A9	Full project funds not available	2.61	1.32	3.37	1.26	9.68	7.01
B. Planning	B1	Inadequate project baseline at the start of execution	3.31	1.02	3.48	1.08	12.25	6.25
	B2	Lack of practical experience while planning	3.24	0.93	3.58	1.00	12.11	5.33
	B3	Lack of consideration of stakeholder requirements in project planning	2.85	0.95	3.05	1.00	9.31	5.02
	B4	Unrealistic activities duration	3.45	0.97	3.71	0.91	13.21	5.97
	B5	Perceiving planning as fulfilling a requirement rather than value added	3.03	1.11	3.13	1.08	10.10	5.79
	B6	Low clarity of scope while planning	3.28	0.97	3.65	1.00	12.46	5.88
	B7	Uncertain labor productivity rates	2.56	1.05	2.88	1.13	8.02	5.78
	B8	Late or no input from subcontractors for sequencing purposes	3.15	1.02	3.29	0.91	10.80	5.47
	B9	Failure to identify schedule requirements for pre-commissioning	3.00	1.09	3.15	1.06	10.05	6.10
	B10	Uncertain quantity identification for planning	2.98	0.99	3.22	1.04	10.04	5.87
	B11	Inadequate project execution plan	2.95	1.12	3.55	1.06	11.01	6.42
	B12	Excessive overlapping of scheduled activities	3.06	1.10	3.47	1.03	11.37	6.40
C. Engineering	C1	Late design deliverables	3.92	0.91	4.01	0.81	16.19	6.05
	C2	Slow response to RFIs	3.14	1.07	3.22	1.12	10.76	6.28
	C3	Uncoordinated designs	3.14	1.06	3.54	1.03	11.87	6.68
	C4	Errors or omissions	2.94	0.99	3.49	1.01	10.70	5.75
	C5	Late vendor information	3.64	1.00	3.62	0.97	13.68	6.54
	C6	Change in design	3.71	1.02	4.04	0.84	15.34	6.00
	C7	Late change in specifications or material of construction	3.07	1.21	3.78	1.08	12.27	6.88
	C8	Lack of constructability /operability /commissioning /startup input	3.24	0.99	3.60	0.93	11.98	5.78
D. Execution	D1	Untimely mobilization	2.56	1.00	2.93	1.03	8.05	5.38
	D2	Lack of consistent use of processes and procedures	2.57	0.91	2.94	0.95	7.96	4.65
	D3	Poor management of subcontractor interfaces to address schedule updates	2.99	0.99	3.17	0.90	9.93	5.18
	D4	Poor management of specifications and/or drawing revisions	2.97	1.03	3.39	1.01	10.57	5.62
	D5	Later owner approval of contract deliverables	3.05	1.14	3.29	1.02	10.49	5.88
	D6	Cash-flow restraints	2.36	1.19	3.11	1.19	8.16	6.23
	D7	Expedited schedule to meet owner’s requirements	3.70	0.95	3.88	0.97	14.65	6.18
	D8	Engineer/architect errors or omissions in Issued for Construction (IFC) documentation	2.97	1.09	3.29	1.08	10.29	6.38
	D9	Site congestion	2.91	1.05	3.01	1.02	9.41	5.80
	D10	Inadequate coordination of site access	2.39	1.09	2.73	0.97	7.17	4.90
	D11	Poor site-layout plan	2.38	0.93	2.78	0.99	7.05	4.34
	D12	Quantity changes	2.90	1.10	3.24	1.01	10.00	6.43
	D13	Late response to Requests for Information (RFIs)	2.92	1.00	3.09	0.93	9.51	5.34
	D14	Excessive Requests for Information (RFIs) by contractors	2.67	1.01	2.89	0.90	8.23	4.91
	D15	Late approval of submittals (example: shop drawings)	2.94	0.99	3.24	1.05	10.10	5.67
	D16	Inadequate risk management	2.70	0.93	3.12	1.05	8.88	5.14
	D17	Schedule pressure	3.74	0.92	3.74	0.91	14.27	5.63
	D18	Achieving schedule milestones by partially completing work	3.08	1.09	3.29	1.10	10.75	6.08
	D19	Funding pressure	2.49	1.18	2.78	1.13	7.99	5.77
	D20	Poor schedule updating and monitoring	3.07	1.04	3.37	1.11	11.07	6.28
	D21	Political instability / security issues	1.75	1.01	2.16	1.25	4.70	5.40

Table 3.3. Continued. The Causes of OOS Work and their Corresponding Likelihood of Occurrence, Relative Impact, and Risk Rating

Causes of Out-of-Sequence Work			Likelihood of Occurrence (L)		Relative Impact (RI)		Risk Rating (RR)	
Description			Mean (1-5)	Std. Dev.	Mean (1-5)	Std. Dev.	Mean (1-25)	Std. Dev.
E. Material Management	E1	Late or deficient owner-furnished items	2.91	1.20	3.48	1.12	10.91	6.62
	E2	Poor procurement strategy	2.87	1.08	3.40	0.99	10.30	5.89
	E3	Late delivery from vendors	3.41	0.93	3.77	0.90	13.07	5.36
	E4	Inadequate expediting/material tracking system	2.86	1.06	3.13	1.09	9.54	5.72
	E5	Insufficient or late vendor data	3.24	0.92	3.40	1.05	11.53	5.75
	E6	Inadequate material storage	2.29	0.90	2.68	1.06	6.68	4.71
	E7	Inadequate vertical transportation (cranes, elevators, etc.)	2.24	1.03	2.93	1.09	7.05	4.92
	E8	Inadequate traffic and logistics	2.02	0.91	2.69	1.09	5.99	4.30
F. Quality Mgmt	F1	Inadequate inspection plans	2.34	0.94	2.96	0.95	7.29	4.57
	F2	Inadequate site inspections (failure to abide by inspection plans)	2.29	0.96	2.82	1.00	6.86	4.65
	F3	Inadequate fabrications / vendors inspections (offsite)	2.74	0.90	3.30	1.04	9.48	5.08
	F4	Bypassing hold points	2.27	0.92	3.06	1.05	7.20	4.69
	F5	Inadequate quality trending	2.27	1.09	2.69	0.96	6.45	4.60
G. Safety Mgmgt	G1	Inadequate safety management practices	1.86	0.94	2.95	1.25	5.77	4.48
	G2	Inadequate planning for required safety practices and site requirements	1.99	1.05	3.00	1.23	6.42	5.22
	G3	Poor integration of safety considerations in design	2.18	1.05	3.14	1.19	7.38	5.46
H. Resource Mgmgt	H1	Shortage of skilled labor	3.08	1.14	3.54	0.96	11.46	6.15
	H2	Staff/craft turnover	2.97	1.11	3.29	0.93	10.35	5.59
	H3	Later-than-planned personnel hiring approval by owner	2.31	1.15	2.79	0.95	7.11	5.12
	H4	Inadequate resource leveling	2.75	1.07	3.00	0.87	8.80	5.23
	H5	High percentage of absenteeism	2.41	1.19	2.83	1.05	7.33	5.15
	H6	Crews having insufficient work to perform (piecemeal work)	2.65	1.11	3.20	0.95	8.93	5.44
	H7	Craft labor agreement issues	2.08	1.12	2.72	1.11	6.52	5.09
	H8	Stacking of trades	2.81	1.13	3.12	0.99	9.46	5.76
I. Change Mgmt	I1	Late scope changes requiring different/new equipment/processes	3.16	1.22	3.89	0.99	12.80	6.56
	I2	Excessive field changes	3.25	1.03	3.73	0.78	12.27	5.22
	I3	Lack of alignment of change order process	2.79	1.05	3.15	0.92	9.14	4.83
	I4	Excessive directed changes	2.78	1.13	3.52	1.03	10.25	5.89
	I5	Rejecting all change orders adding cost or schedule	2.41	1.19	3.35	1.21	8.59	6.16
J. Commissioning	J1	Inadequate commissioning and startup plan	3.07	1.11	3.56	1.05	11.46	5.93
	J2	Late engagement of commissioning group	2.88	1.19	3.32	1.06	10.23	6.12
	J3	Changes of turnover schedule	2.89	1.09	3.25	1.08	10.14	6.21
K. Legal/Commercial Aspects	K1	Lack of consistent contractual flow down to sub-tiers	2.22	1.04	2.58	1.01	6.36	4.77
	K2	Location/social issues/neighbor interventions	1.87	1.02	2.46	1.15	5.33	4.67
	K3	Restrictive / late permitting requirement (ex. environmental)	2.40	1.17	3.11	1.24	8.22	5.94
	K4	Untimely contractual updates with regard to changes	2.23	1.04	2.70	1.19	6.60	4.92
	K5	Delayed payments causing impacts to downstream trades	2.10	1.10	2.77	1.27	6.72	5.48
	K6	Commercial incentive/penalty	2.16	1.06	2.66	1.18	6.46	5.13

3.5.4 The Top Ten Causes of OOS:

The top 10 causes of OOS – based on the risk rating – are shown in Table 3.4. It is logical to see that changes in design and late design deliverables are the top two causes for OOS as they occur the most and result in the highest impacts. The third and fourth top causes are related to schedule pressure to either speed up the delayed project or make changes to meet the owner's new requirements. Moreover, poor communication between parties throughout the project has been shown to have high OOS risks. In addition, scope-related issues such as low clarity and scope changes are significant causes of OOS.

Table 3.4. Top 10 Risky Causes of Out-of-Sequence Work

Code	OOS Cause Description	Category	Ranking by Risk Rating (RR)
C1	Late design deliverables	Engineering	1
C6	Change in design	Engineering	2
D7	Expedited schedule to meet owner's requirements	Execution	3
D17	Schedule pressure	Execution	4
C5	Late vendor information	Engineering	5
E3	Late delivery from vendors	Material Mgmt	6
B4	Unrealistic activities duration	Planning	7
A4	Poor communication between different project parties throughout the project	Project Team	8
I1	Late scope changes requiring different/new equipment/processes	Change Mgmt	9
B6	Low clarity of scope while planning	Planning	10

From discussions with industry experts, it was hypothesized that causes relating to design changes and delays, scope unclarity, schedule pressure, and poor communication were significant causes of OOS that occur most frequently and result in most impacts. The expert-based survey validated this hypothesis by finding that these causes actually have the highest risk ratings as shown in Table 3.4.

The expert-based survey also revealed risky causes that were not expected. For example, late vendor information, albeit being a cause of OOS, was not expected to be one of the top 10 causes of OOS. However, the survey revealed that it has the fifth highest risk rating among the rest of the 88 causes. As such, by knowing this information, project participants should be keen to have complete vendor information at early stages to minimize OOS.

3.5.5 Defining Risk Tiers

To make the ranking easier to understand and more visual, risk tiers were defined. For example, if an OOS cause has a risk rating of 12 (out of 25), what does this mean? is it risky or not? Defining risk tiers, allocating the causes in these risk tiers, and determining the cutoff scores for them answers those questions and makes it easier for users to interpret the risk rating.

At first glance, it may seem practical to just define five risk tiers with equal ranges because the risk rating score ranges from 1 to 25. By equal ranges we mean each tier has a 5-point range. For example, tier 1 takes values from 20 to 25, tier two takes values from 15 to 20 and so on. However, this is not a validated method and is not suitable for this project. As such, a statistical method was utilized to: 1) determine the number of risk tiers, 2) allocate the OOS causes into these risk tiers, and 3) define cutoff scores for the different risk tiers. The method was devised by the author and reviewed by statistics experts at the academic institutions sponsoring the project (University of Tennessee – Knoxville, and University of Wisconsin – Madison).

It is hypothesized that the difference between the relative risks of the OOS causes within the same risk tier is statistically insignificant. So, the methodology is as follows:

- Risk tier #1 has the OOS cause ranked #1.
- Compare between the mean of risk rating of rank #1 and rank #2, then between #1 and #3, then between #1 and #4, and so on until you compare between #1 and #N. Rank #N is the rank where there is a statistically significant difference between #1 and #N. This means that the first risk tier has OOS causes ranked from #1 to #(N – 1).
- For risk tier #2, start from OOS cause ranked #N. Compare between the risk rating mean of #N and #(N+1), then between #N to #(N+2), and so on, until you get to compare #N with #M. Rank #M is the rank where a statistically significant difference between #N and #M is present. This means that the second risk tier has OOS causes ranked from #N to #(M – 1).
- Follow the same logic until you finish all 88 causes of OOS.

By "compare between the means" of two causes, we refer to the Mann-Whitney U test; which is a non-parametric statistical test for comparing between the means of two independent non-normally distributed samples. The test results in a p-value. If the p-value is less than 0.05, then there is a statistically significant difference between the means of the two compared groups. If the p-value is greater than 0.05, then the difference between the compared groups is not statistically significant. Traditionally, the t-test is the one that should be used. However, the t-test requires the data to be normally distributed. Tests of normality were conducted, and it was found that the data is not normally distributed. That is why the Mann-Whitney U test was used instead. Such test does not have normality requirements.

The above-mentioned steps were followed. In short, 6 risk tiers were successfully identified. Table 3.5 shows a summary of the conducted tests between the different risk ratings of the ranked OOS causes. The following sentences provide an explanation to the first few rows of the table. The responses of the respondents for the risk rating of the highest ranked OOS causes are compared to those in the 3rd highest one. The p-value was calculated by the Mann-Whitney U test to be 0.134; which is greater than 0.05. This means that there is no statistically significant difference between OOS cause ranked #1 and that ranked #3 from a risk rating perspective. The same test was conducted between the highest and the 4th highest ranked OOS cause and a statistically significant difference was found. This means that the 4th highest ranked OOS cause does not belong to the same risk tier as those ranked #1, #2, and #3.

Table 3.5. Obtaining the OOS Risk Tiers through Statistical Analysis

Comparing between the Mean Risk Rating of Which Ranked Causes?	P-value	Significance at α =0.05	Conclusion
1st rank with 3rd rank	0.134	Statistically Insignificant	Risk Tier 1 contains OOS Causes from rank #1 to #3
1st rank with 4th rank	0.05	Statistically Significant	
4th rank with 10th rank	0.61	Statistically Insignificant	Risk Tier 2 contains OOS Causes from rank #4 to #10
4th rank with 11th rank	0.016	Statistically Significant	
11th rank with 39th rank	0.102	Statistically Insignificant	Risk Tier 3 contains OOS Causes from rank #11 to #39
11th rank with 40th rank	0.036	Statistically Significant	
40th rank with 58th rank	0.062	Statistically Insignificant	Risk Tier 4 contains OOS Causes from rank #40 to #58
40th rank with 59nd rank	0.026	Statistically Significant	
59th rank with 83rd rank	0.057	Statistically Insignificant	Risk Tier 5 contains OOS Causes from rank #59 to #85
59th rank with 84th rank	0.003	Statistically Significant	
84th rank with 88th rank	0.06	Statistically Insignificant	Risk Tier 6 contains the rest of the OOS Causes

3.5.5.1 <u>Cutoff Scores between Tiers:</u>

To determine the cutoff score between the different risk tiers, Equation 3.2 is used. For example, since the OOS cause ranked #3 is the last one in tier #1 and the cause ranked #4 is the first one in tier #2, the cutoff score between tier #1 and tier #2 is the midpoint between the risk rating of OOS ranked #3 and that ranked #4. By applying Equation 3.2, the cutoff scores separating between the different risk tiers were determined.

$$Cutoff_{x,x+1} = \frac{RR_{x(high)} + RR_{x+1(low)}}{2} \qquad \text{Eq. (3.2)}$$

$Cutoff_{x,x+1}$: Cutoff Risk Rating Score sore between Tier X and Tier X+1

$RR_{x(high)}$: Mean Risk Rating of the highest ranked OOS cause in Tier X

$RR_{x+1(low)}$: Mean Risk Rating of the lowest ranked OOS cause in Tier X+1

Table 3.6 shows the different risk tiers and their associated cutoff scores that were determined through applying Equation 3.2. Figure 3.5 provides a visual representation of the risk rating ranges defining the risk tiers. As shown in Figure 3.5, the 6 risk tiers do not have equal ranges. Also, most of the OOS causes are found in Tiers 3, 4, and 5. Project participants should concentrate on eliminating the causes in Tier 1 and Tier 2 because they hold the greatest risks on the project. They also should address the OOS causes in the other risk tiers.

Table 3.6. The OOS Risk Tiers and their Associated Cutoff Scores.

	Risk Rating Limits (Cutoff Scores)		From the 88 Causes of OOS, Which Ones are in Which Tier?	Number of OOS Causes Present in Each Risk Tier
	Min	Max		
Tier 1	14.46	25	from Rank 1 to Rank 3	3
Tier 2	12.365	14.46	From Rank 4 to Rank 10	7
Tier 3	10.075	12.365	From Rank 11 to Rank 39	28
Tier 4	8.225	10.075	From Rank 40 to Rank 58	24
Tier 5	6.205	8.225	From Rank 59 to Rank 83	21
Tier 6	0	6.205	From Rank 84 to Rank 88	5

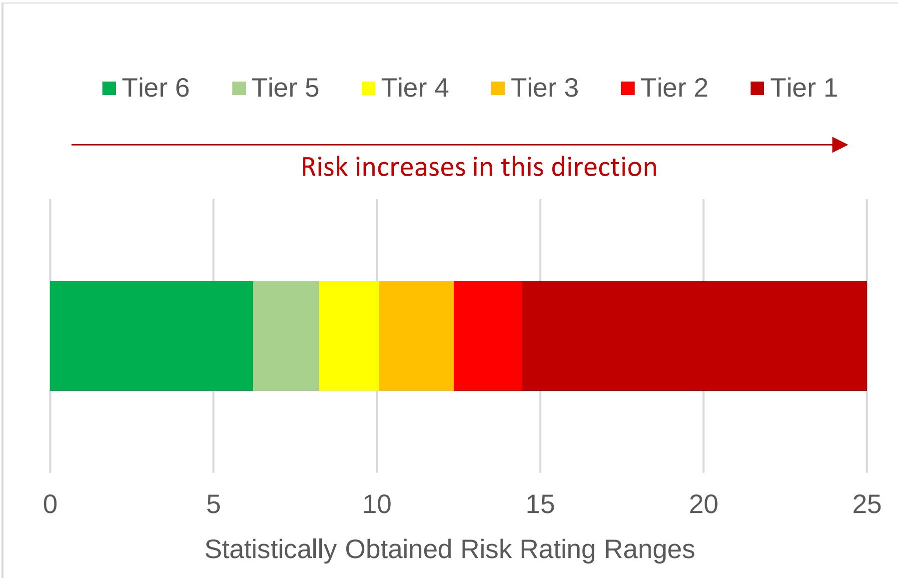


Figure 3.5. Visual Representation of the Risk Rating Ranges Defining the Risk Tiers.

3.5.5.2 <u>The OOS Risk Tier Curves</u>

Risk tiers are functions of the risk rating, and the risk rating is a function of the likelihood of occurrence and the relative impact. From that, a graph having curves that represent the cutoff regions for the different risk tiers based on the likelihood of occurrence and relative impact of OOS causes was developed and presented in Figure 3.6. Users can use this curve in assessing any factor that leads to OOS. If they know the likelihood of occurrence and relative impact of that cause, they can plot the cause as a point in Figure 3.6. Depending on the point's location, the user will be able to easily know which risk tier this OOS cause belong to.

3.5.5.3 <u>Risk Tiers of the Studied Causes of OOS</u>

After the risk tiers were defined, the 88 causes of OOS were assigned to them. Table 3.7 shows the causes of OOS and their corresponding risk tiers. The table should be helpful for project participants with limited resources who would like to utilize their resources in addressing the causes of OOS in order of their risk tiers.

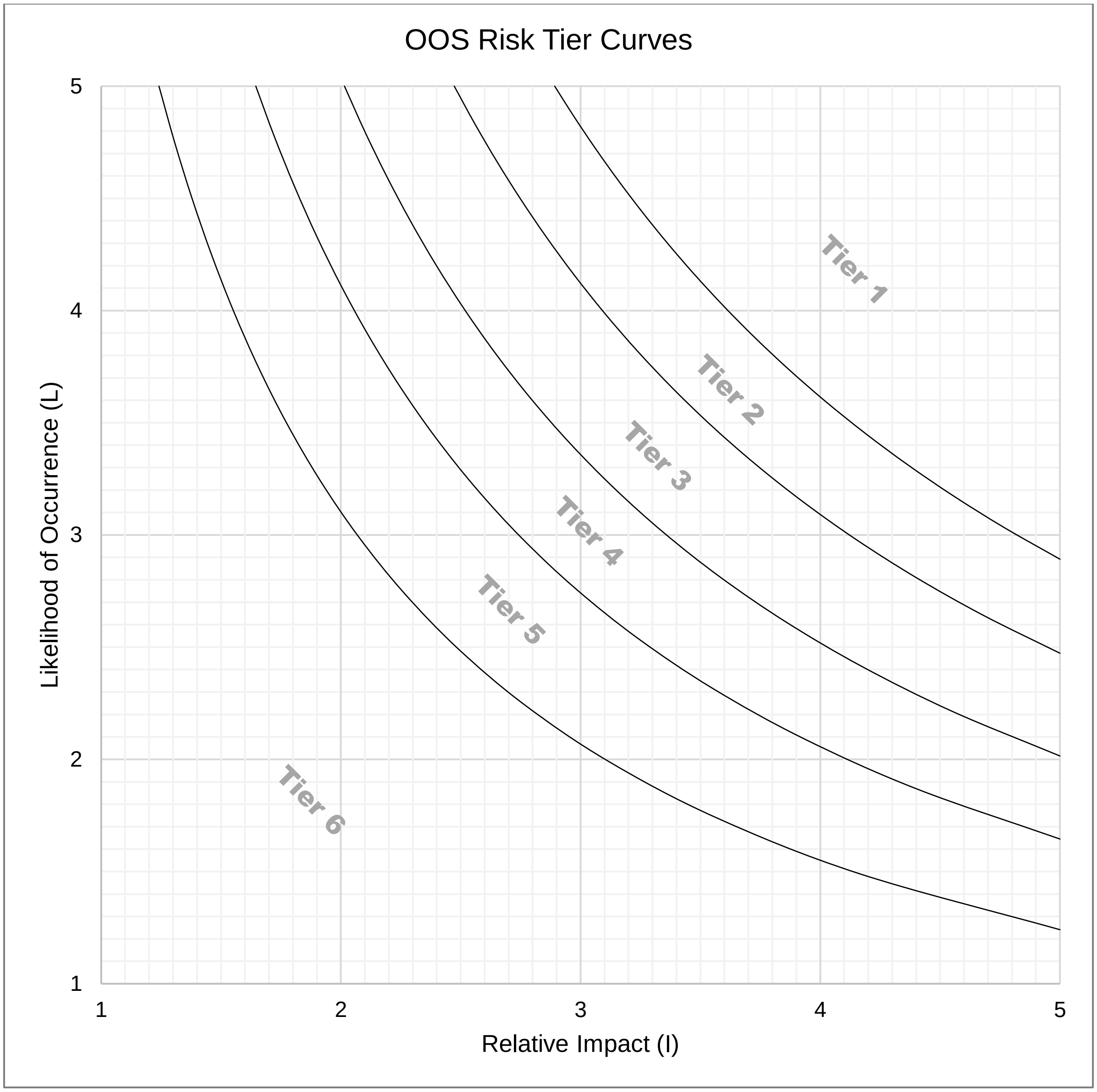


Figure 3.6. OOS Risk Tier Curves

Table 3.7. Causes of OOS, their Overall Risk Ranking, and their Risk Tiers

Causes of Out-of-sequence Work			Risk Rating (RR)	Ranking	Risk Tier
Category	Code	Description	Mean (1-25)	(1-88)	
A. Project Team	A1	Lack of team alignment	10.26	32	Tier 3
	A2	Leadership deficiency	9.99	42	Tier 4
	A3	Project chain of command not properly established/followed	8.71	56	Tier 4
	A4	Poor communication between different project parties throughout the project	12.79	8	Tier 2
	A5	Inappropriate team size	6.93	69	Tier 5
	A6	Not enough attention to periodical meetings	6.01	83	Tier 6
	A7	Lack of project team experience relative to type and size of project	10.53	21	Tier 3
	A8	Social and political influences within the project team	6.04	84	Tier 6
	A9	Full project funds not available	9.55	45	Tier 4
B. Planning	B1	Inadequate project baseline at the start of execution	12.19	13	Tier 3
	B2	Lack of practical experience while planning	11.87	14	Tier 3
	B3	Lack of consideration of stakeholder requirements in project planning	9.40	51	Tier 4
	B4	Unrealistic activities duration	13.05	6	Tier 2
	B5	Perceiving planning as fulfilling a requirement rather than value added	10.09	39	Tier 3
	B6	Low clarity of scope while planning	12.70	10	Tier 2
	B7	Uncertain labor productivity rates	8.37	62	Tier 4
	B8	Late or no input from subcontractors for sequencing purposes	10.86	25	Tier 3
	B9	Failure to identify schedule requirements for pre-commissioning	10.00	40	Tier 4
	B10	Uncertain quantity identification for planning	9.99	41	Tier 4
	B11	Inadequate project execution plan	11.27	23	Tier 3
	B12	Excessive overlapping of scheduled activities	11.18	20	Tier 3
C. Engineering	C1	Late design deliverables	16.35	1	Tier 1
	C2	Slow response to RFIs	10.85	26	Tier 3
	C3	Uncoordinated designs	11.95	16	Tier 3
	C4	Errors or omissions	10.66	28	Tier 3
	C5	Late vendor information	13.68	5	Tier 2
	C6	Change in design	15.41	2	Tier 1
	C7	Late change in specifications or material of construction	12.42	11	Tier 2
	C8	Lack of constructability /operability /commissioning /startup input	11.82	15	Tier 3
D. Execution	D1	Untimely mobilization	8.33	61	Tier 4
	D2	Lack of consistent use of processes and procedures	8.13	64	Tier 5
	D3	Poor management of subcontractor interfaces to address schedule updates	9.77	44	Tier 4
	D4	Poor management of specifications and/or drawing revisions	10.75	29	Tier 3
	D5	Later owner approval of contract deliverables	10.69	30	Tier 3
	D6	Cash-flow restraints	8.01	60	Tier 5
	D7	Expedited schedule to meet owner’s requirements	14.55	3	Tier 1
	D8	Engineer/architect errors or omissions in Issued for Construction (IFC) documentation	10.66	34	Tier 3
	D9	Site congestion	9.36	50	Tier 4
	D10	Inadequate coordination of site access	7.08	70	Tier 5
	D11	Poor site-layout plan	7.03	72	Tier 5
	D12	Quantity changes	10.20	42	Tier 3
	D13	Late response to Requests for Information (RFIs)	9.65	47	Tier 4
	D14	Excessive Requests for Information (RFIs) by contractors	8.33	58	Tier 4
	D15	Late approval of submittals (example: shop drawings)	10.36	38	Tier 3
	D16	Inadequate risk management	8.83	54	Tier 4
	D17	Schedule pressure	14.05	4	Tier 2
	D18	Achieving schedule milestones by partially completing work	10.77	27	Tier 3
	D19	Funding pressure	8.00	63	Tier 5
	D20	Poor schedule updating and monitoring	11.09	21	Tier 3
	D21	Political instability / security issues	4.61	88	Tier 6
E. Material Management	E1	Late or deficient owner-furnished items	11.13	24	Tier 3
	E2	Poor procurement strategy	10.41	33	Tier 3
	E3	Late delivery from vendors	13.21	7	Tier 2
	E4	Inadequate expediting/material tracking system	9.61	46	Tier 4
	E5	Insufficient or late vendor data	11.57	17	Tier 3
	E6	Inadequate material storage	6.78	76	Tier 5
	E7	Inadequate vertical transportation (cranes, elevators, etc.)	7.24	72	Tier 5
	E8	Inadequate traffic and logistics	6.22	85	Tier 5

Table 3.7. Continued. Causes of OOS, their Overall Risk Ranking, and their Risk Tiers

Causes of Out-of-sequence Work			Risk Rating (RR)	Ranking	Risk Tier
Category	Code	Description	Mean (1-25)	(1-88)	
F. Quality Mgmt	F1	Inadequate inspection plans	7.48	67	Tier 5
	F2	Inadequate site inspections (failure to abide by inspection plans)	7.10	74	Tier 5
	F3	Inadequate fabrications / vendors inspections (offsite)	9.84	48	Tier 4
	F4	Bypassing hold points	7.32	68	Tier 5
	F5	Inadequate quality trending	6.43	80	Tier 5
G. Safety Mgmgt	G1	Inadequate safety management practices	5.87	86	Tier 6
	G2	Inadequate planning for required safety practices and site requirements	6.57	81	Tier 5
	G3	Poor integration of safety considerations in design	7.48	65	Tier 5
H. Resource Mgmgt	H1	Shortage of skilled labor	11.82	18	Tier 3
	H2	Staff/craft turnover	10.33	31	Tier 3
	H3	Later-than-planned personnel hiring approval by owner	6.96	71	Tier 5
	H4	Inadequate resource leveling	8.69	55	Tier 4
	H5	High percentage of absenteeism	7.35	66	Tier 5
	H6	Crews having insufficient work to perform (piecemeal work)	8.87	53	Tier 4
	H7	Craft labor agreement issues	6.54	78	Tier 5
	H8	Stacking of trades	9.48	49	Tier 4
I. Change Mgmt	I1	Late scope changes requiring different/new equipment/processes	12.76	9	Tier 2
	I2	Excessive field changes	12.21	11	Tier 3
	I3	Lack of alignment of change order process	9.13	52	Tier 4
	I4	Excessive directed changes	10.26	35	Tier 3
	I5	Rejecting all change orders adding cost or schedule	8.59	57	Tier 4
J. Commissioning	J1	Inadequate commissioning and startup plan	11.22	19	Tier 3
	J2	Late engagement of commissioning group	9.87	36	Tier 4
	J3	Changes of turnover schedule	10.01	37	Tier 4
K. Legal/Commercial Aspects	K1	Lack of consistent contractual flow down to sub-tiers	6.57	82	Tier 5
	K2	Location/social issues/neighbor interventions	5.50	87	Tier 6
	K3	Restrictive / late permitting requirement (ex. environmental)	8.37	59	Tier 4
	K4	Untimely contractual updates with regard to changes	6.67	77	Tier 5
	K5	Delayed payments causing impacts to downstream trades	6.72	75	Tier 5
	K6	Commercial incentive/penalty	6.76	79	Tier 5

3.5.6 Early Warning Signs of OOS

Early warning signs: are events that are somehow correlated to, but do not necessarily directly cause, out-of-sequence work. In other words, when these events occur in a project, then one will have a feeling that OOS will probably take place. The respondents were asked to rate these early warning signs (from 1 to 5). This rating indicates the strength of correlation between early warning signs and OOS. The following table shows the respondents' answers related to the rating of the early warning signs.

The respondents were asked this question: How strongly are the following early warning signs correlated to OOS? (i.e. if any of these situations occurred, how strongly will you be worried that out-of-sequence work will take place later in the project? The early warning signs and their resulting correlation to OOS work is presented in Table 3.8. The table also shows the ranking of the early warning signs.

3.5.6.1 Top 10 Early Warning Signs

Some of the highly ranked early warning signs were in line with the common knowledge, such as late purchase orders, high frequency of change, high percentage of rework. It is logical that by making purchase orders late, the purchased material will be late, leading to OOS work. Also, high percentage of rework is also known to be correlated to OOS that causes even more rework in a vicious cycle.

The expert-based survey revealed early warning signs that are not anticipated or expected from common knowledge. For example, according to the results, "higher wages elsewhere" is one of the highest rated early warning signs. Despite construction parties do not take this wage differential into high consideration while assessing the project risks, it seems that this problem have affected several of the respondents. Higher wages in neighboring projects lead to workers leaving the project. In return, getting new labor and training them would lead to inefficiencies that result in OOS. Based on that, it is now essential for project parties to study the labor wages in neighboring projects and devise proper actions to minimize the turnover rate.

Table 3.8. Early Warning Signs of OOS

Category	No.	Early warning signs	Mean Rating (1-5)	Std. Dev	Ranking
A. Project Team	A1	Poorly planned kickoff meeting.	2.84	1.07	49
	A2	Inexperience in key roles.	3.61	0.89	18
	A3	Changing operations personnel from design meetings to construction.	2.95	0.97	44
B. Planning	B1	Multiple Issued for Construction (IFC) with holds releases during civil & structural work.	3.71	1.04	12
	B2	Up and down quantity trends.	3.05	1.12	39
	B3	Project weekly meeting is focused on numbers not information.	2.87	1.08	48
	B4	Early usage of float in schedule.	3.54	0.99	20
	B5	Initial schedule extending past clients wishes.	3.48	1.14	25
	B6	Team members not providing important information about next week’s work.	3.54	0.99	20
	B7	Project team focused on showing good numbers rather than proactive actions.	3.63	1.05	16
	B8	Planner coming with experience in different type of project	2.80	1.11	50
C. Engineering	C1	Engineering risks taken by modifying their standard procedures and work processes.	2.95	1.02	43
	C2	Increase in drawings revisions.	3.70	0.97	13
	C3	Late Design specifications.	3.77	1.09	9
	C4	Client issued specifications not meeting current codes.	3.07	1.20	36
	C5	Continued discussions on specific process requirements	3.51	0.98	23
	C6	Difficulty in getting systems input	3.15	1.04	34
D. Execution	D1	Project decisions that do not support original plan.	3.51	0.89	22
	D2	Construction team using outdated drawings, or drawings with holds.	3.78	1.14	8
	D3	Weekly meetings focused on work assessment rather than discussing planned work or unplanned situations.	3.35	0.92	30
	D4	Float usage early in schedule.	3.51	0.95	23
	D5	High/growing percentage of critical activities in schedule.	4.10	0.73	3
	D6	High number of open employee requisition	2.96	0.99	42
	D7	Trending away from baseline progress curve	3.74	0.99	11
E. Material Management	E1	Late Purchase Orders (PO’s)	3.79	0.94	5
	E2	Fabrication holds	3.63	1.11	16
	E3	Vendor data & inspections behind schedule	3.78	0.96	6
F. Quality Management	F1	High percentage of rework.	3.76	0.94	10
	F2	Inadequate quality management personnel	3.99	0.84	4
	F3	High percentage of NCRs	3.19	0.99	32
G. Safety Management	G1	Project decisions that do not support original plan of safe execution	3.45	0.90	26
	G2	Adverse safety performance trends	3.21	1.21	31
	G3	Shortage of safety professionals	3.43	1.19	27
H. Resource Management	H1	Delayed placement of major equipment orders.	2.68	1.03	52
	H2	Higher wages elsewhere	4.11	0.86	2
	H3	Area recruiting increases.	2.90	0.94	47
	H4	Exit interview – “leaving to work elsewhere”.	2.72	0.96	51
	H5	Increase in projects in the area.	2.63	1.06	53
	H6	Trending away from baseline progress curve.	2.92	0.96	46
	H7	Slow buildup of manpower loading curve.	3.41	1.05	29
I. Change Management	I1	No client representative with project team.	3.16	0.92	33
	I2	Changing operations personnel during model reviews.	3.05	1.21	38
	I3	Late decisions on change	2.97	1.03	41
	I4	High frequency of change	3.78	0.98	7
J. Commissioning	J1	Late start of pre-commissioning activities.	4.22	0.85	1
	J2	Lack of clear systems-based turnover processes.	3.42	0.89	28
	J3	Inadequate transition planning from construction to commissioning	3.57	1.02	19
K. Legal/Commercial Aspects	K1	Neighborhood complaints upon mobilization.	3.68	1.07	14
	K2	Different versions of drawings on site.	2.24	1.02	54
	K3	Early coordination issues (starting at site mobilization).	3.64	1.19	15
	K4	Inadequate status reports on permitting.	3.06	0.92	37
	K5	Permit questions during detailed design.	3.04	1.03	40
	K6	No clearly identified person to follow up on permits.	3.08	0.92	35
	K7	Extra-ordinary emphasis on cash flow planning/management.	2.95	1.15	45

3.5.7 Impacts of OOS

In this section, the respondents were asked to rate the relative impact of OOS on schedule, productivity, cost, quality, and safety. Table 4.9 shows the results and Figures 3.7 and 3.8 visually demonstrate them.

As expected, OOS has the strongest impact on schedule and productivity and the least impact on safety. These results are well-aligned with the literature indicating the OOS negatively impacts the schedule, which impacts productivity, which in turn impacts the project cost. If we look at the distribution of the respondents' answers (Figure 3.8), we can find that around 85% of the surveyed experts stated that OOS has significant to extreme impacts on schedule overrun. Also, around 74% stated that OOS has significant to extreme impacts on productivity, and 73% stated it has significant to extreme impacts on cost. These percentages are significant as they highlight the importance of minimizing OOS as a mean to minimize schedule overruns, productivity loss, and cost overruns.

3.5.8 Comparison between Owners and Contractors

The responses of the owners and those of the contractors are separated and compared to investigate the current status of alignment between the two parties when it comes to their perception of OOS. The total number of responses was 27 for owners and 29 for contractors. It shall be noted that, by "owner" we mean the respondents whose companies act as owners only (not working as both owners and engineers at the same time). Also, by "contractor" we mean the respondents whose companies act as contractors only.

To check whether the responses of the owners are different from those of contractors, a statistical test of comparing means of two independent is performed. If the data is normally distributed, then the t-test should be used. If the data is not normally distributed, then the Mann-Whitney U test should be used because it does not assume normality. The followed procedure is clarified in Figure 3.9.

Table 3.9. Relative Impact of OOS Work on Main Project Attributes.

Impacts of OOS on	Mean Impact (1-5)	Std. Dev.
Schedule overrun	4.13	0.80
Productivity loss	3.93	0.77
Cost overrun	3.83	0.85
Quality decline	3.31	0.93
Safety risks	3.12	1.06

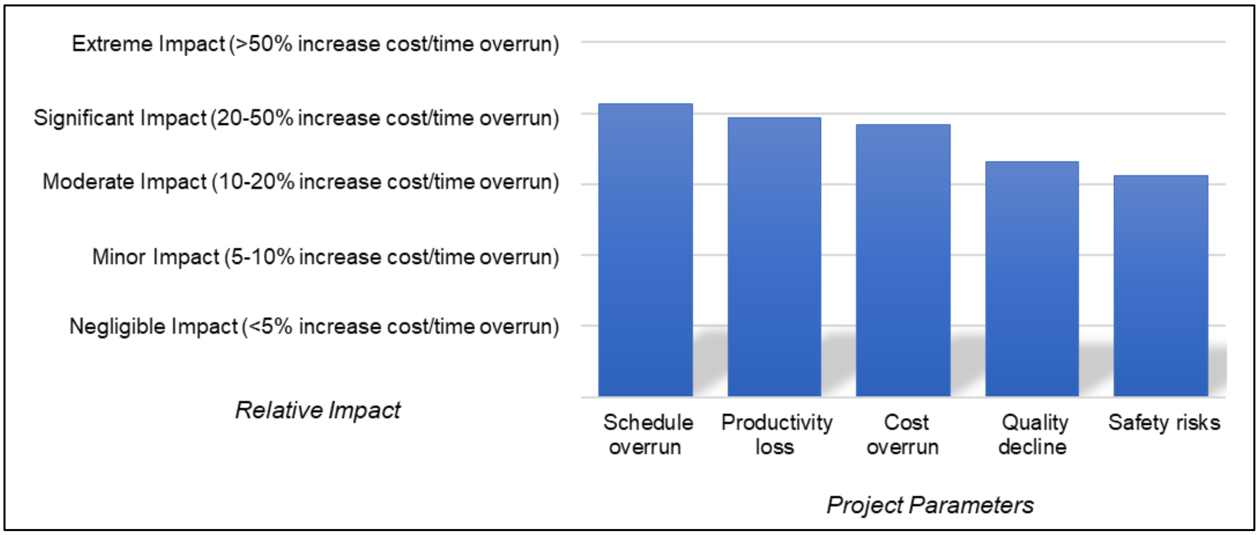


Figure 3.7. Mean Relative Impact of OOS on Main Project Attributes.

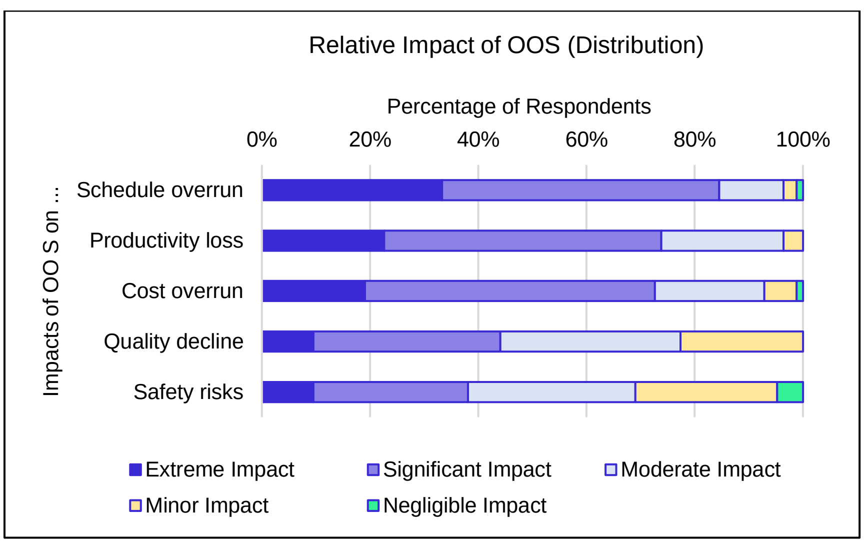


Figure 3.8. Distribution of the Respondents’ Answers with Regards the Impacts of OOS.

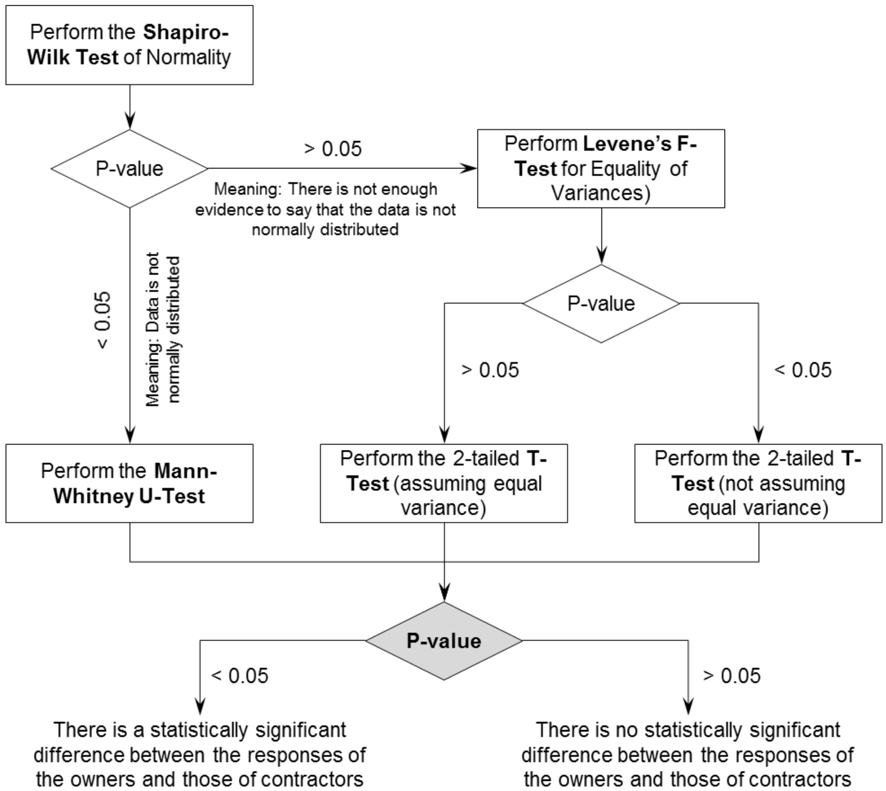


Figure 3.9. The Used Procedure to Test between Owners' and Contractors' Responses.

The conducted tests enabled identifying the points that owners and contractors perceive differently. The Shapiro-Wilk test showed that we cannot consider the data normally distributed. So, the Mann-Whitney U-test was conducted to compare means. If the p-value is less than 0.05, then there is a statistically significant difference between the owners' answers and the contractors' answer.

3.5.8.1 Comparing between Owners and Contractors Related to the General Frequency and Impacts of OOS Work

By analyzing the responses of the owners and contractors to the questions related to the general frequency and impact of OOS work, it was found that contractors perceive OOS as a problem that occurs more often and has more impacts than what the owners perceive. There is a statistically significant difference between the owners' answers and the contractors' answers in the question that asked about the frequency of occurrence of OOS. This difference is realistic since contractors might tend not to report minor OOS to the owner. However, this also shows the lack of alignment between owners and contractors. In perfect situations, owners and contractors should have the same perception of OOS frequency and impact in their projects.

Table 3.10. Frequency and Impact of OOS Work in the Industry

Survey Questions	Owners		Contractors		P-value for Mann-Whitney U Test
	Mean Rating	Std. Dev	Mean Rating	Std. Dev	
1. How **frequently** do you typically encounter OOS in your projects?	3.04	0.81	3.72	0.88	0.005
2. How would you rate the negative **impacts** of out-of-sequence (OOS) work in construction projects?	3.15	0.86	3.59	0.82	0.061

3.5.8.2 Comparing between Owners and Contractors Related to the Causes of OOS Work

Only two out of the 88 causes had statistically significant difference between owners and contractors in terms of their perception of the likelihood of occurrence of those causes. Table 3.11 shows only those two causes and their corresponding information, including the p-value of the conducted statistical test. In both causes, namely 1) failure to identify schedule requirements for pre-commissioning and 2) inadequate quality trending, owners stated that these causes occur much more likely than what contractors stated. This could be correct or could be due to bias since both causes are mainly shortcomings from the contractor's side. Either ways, this indicates lack of alignment between owners and contractors. Other than those two causes, it was noticed that contractors put higher likelihood ratings in causes that are triggered by owners and less likelihood ratings in causes that are triggered by themselves. On the other hand, owners put higher likelihood ratings in causes that are triggered by contractors and less likelihood ratings in causes that are triggered by themselves. However, these differences are statistically insignificant, that is why they were not included in Table 3.11.

Table 3.11. Causes with Statistically Significant Differences between Owners and Contractors in the Likelihood of Occurrence

Causes of OOS Work	Mean of Likelihood of Occurrence (1-5)		Corresponding Standard Deviation		P-Value
	Owners	Contractors	Owners	Contractors	
B9. Failure to identify schedule requirements for pre-commissioning	3.15	2.55	1.13	1.09	0.041
F5. Inadequate quality trending	2.48	1.79	1.37	0.63	0.046

With regards to the <u>relative impact</u>, 10 out of the 88 causes had statistically significant difference as shown in Table 3.12, namely 1) Poor communication between different project parties throughout the project, 2) Uncertain quantity identification for planning, 3) Excessive overlapping of scheduled activities, 4) Late design deliverables, 5) Later owner approval of contract deliverables, 6) Expedited schedule to meet owner's requirements, 7) Quantity changes, 8) Late approval of submittals, 9) Excessive field changes, and 10) Rejecting all change orders adding cost or schedule. In these 10 causes, the contractors stated that their impacts are higher than what the owners stated.

Table 3.12. Causes with Statistically Significant Differences between Owners and Contractors in the Relative Impact

Causes of OOS Work	Mean of Likelihood of Occurrence (1-5)		Corresponding Standard Deviation		P-Value
	Owners	Contractors	Owners	Contractors	
A4. Poor communication between different project parties throughout the project	3.38	3.89	0.94	0.63	0.046
B9. Uncertain quantity identification for planning	2.73	3.37	1.00	1.01	0.021
B12. Excessive overlapping of scheduled activities	3.11	3.67	1.05	0.92	0.035
C1. Late design deliverables	3.67	4.21	0.88	0.79	0.023
D5. Later owner approval of contract deliverables	2.65	3.39	0.94	0.88	0.007
D7. Expedited schedule to meet owner's requirements	3.31	4.19	1.09	0.74	0.003
D12. Quantity changes	2.73	3.32	0.96	0.94	0.033
D15. Late approval of submittals (example: shop drawings)	2.77	3.41	0.95	1.01	0.029
I2. Excessive field changes	3.46	3.93	0.76	0.77	0.018
I5. Rejecting all change orders adding cost or schedule	2.73	3.56	1.19	1.12	0.014

Moreover, in most of the causes other than the ones in Table 3.12. – albeit without statistically significant differences, the same pattern of contractors stating higher impacts than owners immerges but in a lesser strength. This could be interpreted in any of the following interpretations (or a combination of them): (1) contractors are overestimating the impacts of the OOS causes; (2) owners are underestimating the impacts of OOS, or (3) contractors take most of the damage when OOS takes place, leading to more impacts on them and lesser impacts on the owners. In all cases, no matter what the interpretation is, this shows that contractors and owners are not aligned when it comes to quantifying the impacts of 11% of the OOS causes. Two of these causes are in risk tier #1, knowing that this risk tier has only three causes. Most of rest of causes with statistically significant differences are in risk tier #3.

3.5.8.3 Comparing between Owners and Contractors Related to the Early Warning Signs of OOS Work

Among the 54 early warning signs of OOS, only one has a statistically significant difference between owners and contractors. Contractors claim that late decision on change (which is the owner's responsibility) has higher correlation to OOS than what the owners claim, as shown in Table 3.13. However, both the owners and contractors still perceive that there is high correlation (their mean rating is above 3). The only difference is that contractors perceive more correlation than the owners perceive. There is not significant lack of alignment between owners and contractors when it comes to the rest of the early warning signs of OOS.

Table 3.13. Early Warning Signs with Statistically Significant Differences between Owners and Contractors.

Early Warning Signs of OOS Work	Strength of Correlation to OOS (1-5)		Corresponding Standard Deviation		P-Value
	Owners	Contractors	Owners	Contractors	
I3. Late decisions on change	3.40	3.92	0.82	1.00	0.02

3.5.8.4 Comparing between Owners and Contractors Related to the Impacts of OOS Work

Generally, contractors stated that the impacts of OOS on schedule, productivity, cost, quality, and safety are more severe than what the owner stated as shown in Table 3.14. Out of the five project attributes, three had statistically significant differences; which is not a small percentage. Contractors perceive OOS as a strong cause for schedule overruns, quality decline, and safety risks more than what owners perceive. This significant difference indicates the week alignment between owners and contractors when it comes to assessing the impacts of OOS. It also might indicate that owners underestimate the impacts of OOS or contractors overestimate the impacts of OOS. In all cases, this differential in the responses should trigger researchers to develop means of fairly assessing the impacts of OOS in construction projects, as none exist in the current practice.

Table 3.14. Comparing between Owners and Contractors in Relation to the Impacts of OOS Work.

Impacts of OOS on	Mean Impact (1-5)		Standard Deviation		P-value
	Owners	Contractors	Owners	Contractors	
Schedule overrun	3.62	4.07	0.85	0.68	0.04
Productivity loss	3.00	3.15	0.94	1.06	0.59
Cost overrun	3.12	3.37	0.99	0.79	0.31
Quality decline	3.58	4.11	0.70	0.70	0.01
Safety risks	3.96	4.41	0.72	0.64	0.02

3.6 Sample Size Analysis

A question rises here: is the overall sample size sufficient to represent the industry? In order to generalize the results and be able to claim that they represent the current status of the industry – or at least the geographic locations of the CII member companies, we have to make sure that the sample size is sufficient. The sample size was 88 respondents.

Fowler (1995) suggests the minimum sample size to be from 15 to 35 respondents. Sudman (1983) suggests the minimum sample size to be from 20 to 50 respondents. Converse and Presser (1986) suggest the minimum sample size to be from 25 to 75 respondents. By all of these suggestions, the sample size in this research (88 respondents) is acceptable.

Also, to have more confidence in the sample size, a statistical method is used using Equation 3.3 and Equation 3.4. These equations are widely used in statistical applications to calculate the needed sample size that is sufficient for estimating the estimate population mean.

$$n = \frac{z^2 s^2}{d^2} \qquad \text{Eq. (3.3)}$$

$$s = s' \sqrt{\left(\frac{n'}{n' - 1}\right)} \qquad \text{Eq. (3.4)}$$

Where, n: minimum sample size, z: standard normal deviation (at 95% confidence level, z = 1.96), d: acceptable standard error of mean, s: population standard deviation, s': sample standard deviation, and n': available sample size.

If the total population was to answer the 245 questions of the survey, each of the question would have a different standard deviation. So, it was assumed that the sample standard deviation is equal to the population standard deviation; which is a valid assumption made by several statisticians in similar situations. In this case, the equation was applied to every question in the survey, once in the pilot study and once in the final study (because every question has its own standard deviation) and obtained the minimum number of respondents required to answer each question. The equation was attempted with several values of d. Table 3.15 shows the most conservative results with the different values of d.

Table 3.15. Sample Size Analysis.

Acceptable standard error of mean	Minimum number of required responses (sample size)	Average
12.5% = 0.5	From 6 to 32	17
10% = 0.4	From 9 to 50	26
7.5% = 0.3	From 17 to 89	47
6.25% = 0.25	**From 24 to 128**	**67**
5% = 0.2	From 38 to 199	105

According to Table 3.15, if we accept a standard error of 6.25%, the resulting minimum number of respondents ranges from 24 to 128 (each question in the survey requires a different sample size based on its variance to maintain the desired standard error of mean). On average, the questions required a sample size of 67 to maintain a standard error of 6.25%. Since the expert-based survey has a larger sample size (88 responses), ***it can be concluded that the sample size is sufficient***. If a standard error of 5% was desired, then a sample size of 105 would be required. However, a 6.5% standard error is acceptable.

3.7 The OOS Rating Score

3.7.1 Mathematical Formulation

An OOS Rating Score; which is a certain score that is calculated for any project at the planning phase was developed. Such score represents the expected severity of OOS in the project. Each cause has a rating for likelihood and impact on a scale from 1 to 5. For any project in the planning phase, the project stakeholder can select only the causes which apply to his/her project, from the 88 available causes; meaning that he/she selects those causes that he/she expects they might take place given the project's current management practices. For example, if the project does not use BIM, then he/she would select the causes that relate to coordination mistakes in design.

After selecting the relevant causes, two scores are calculated, namely the "Project OOS Rating Score" and the "Industry OOS Rating Score". The Project OOS Rating Score is calculated by multiplying the likelihood of occurrence of each of the OOS causes (value inputted by the user) by its corresponding relative impact (value obtained from the survey's results) to obtain its risk rating, then getting the average of all risk ratings of the selected causes of OOS, as shown in Equation 3.5. This score represents how prone is the project to OOS work. The Industry OOS Rating Score is calculated exactly similar to the Project OOS Rating Score but with only one difference. In the Industry OOS Rating Score, values for the likelihood of occurrence are obtained from the survey's results that represent the industry's averages.

The OOS Rating Score, for both the project and industry, ranges from 1 to 25; which is the same range of the risk rating of any cause of OOS. As such, there are six OOS risk tiers that a project can fall under. The scores corresponding to those risk tiers are presented in Table 3.6. For example, if the Project OOS Rating Score is 10 out of 25, this means that it lies in risk tier 4; which is not alarming.

For any project, if the resulting Project OOS Rating is high, the stakeholder will be alarmed to take preventive actions that would decrease the inputted likelihood of the selected OOS causes. Generally, project stakeholders should make managerial policies that would enhance the project conditions and try to lower the Project OOS Rating Score as much as they can. Project participants are recommended to avoid being in the first two risk tiers. Moreover, stakeholders can compare the Project OOS Rating to the Industry OOS Rating to have a better idea on whether their project is more or less prone to OOS compared to the average projects in the industry. It goes without saying that the project participants must thrive to always have a Project OOS Rating Score that is lower than the Industry OOS Score; in addition to avoiding being in the first two risk tiers.

$$Project\ OOS\ Rating\ Score\ R_P = \frac{1}{n}\sum_{i \in K} P_i I_i \qquad \text{Eq. (3.5)}$$

$$Industry\ OOS\ Rating\ Score\ R_I = \frac{1}{n}\sum_{i \in K} L_i I_i \qquad \text{Eq. (3.6)}$$

Where,

- The term i represents the code number of the OOS causes. Since there are 88 causes, therefore i can be any number from 1 to 88.
- The term K is the set of only the OOS causes selected by the project stakeholder. So, for example, if the user selected the causes numbered 5, 10, 12, and 24; then $K = \{5, 10, 12, 24\}$ in this case.
- The term P_i represents the likelihood of occurrence of an OOS cause number i as expected by the stakeholder. The value of P_i is inputted by the user. It ranges from 1 to 5. Section 3.5.2 provides detailed description of the representation of each value.
- The term L_i represents the industry's average of the likelihood of occurrence of the OOS cause number i. The value of L_i is obtained from Table 3.3 under the column named "Likelihood of Occurrence - mean 1-5".
- The term I_i represents the average relative impact of the OOS cause number i in the industry. The value of L_i is obtained from Table 3.3 under the column named "Relative Impact - mean 1-5".
- The term N represents the total number of OOS causes. So $N = 88$.

- The term n represents the number of OOS causes that are selected by the user. So, logically $n \leq N$.

- The term R represents the OOS Rating Score. The minimum value of R is 0. The maximum value of R is 25 (where P and I are at their maximum).

If no conditions are set, the OOS rating will not be a good representative in extreme cases where. For example, if the user only selects one OOS cause with high value of I and he/she inputs a high value of P, the resulting OOS Rating will be very high although there is only one OOS cause selected out of the 88 ones; which does not make sense. Accordingly, a condition should be added to make sure the OOS Rating is standardized even in extreme cases. This condition is as follows:

Condition: The user has the freedom to choose the OOS causes of concern, but in all cases, **the term $\boldsymbol{n}$ should not be less than 10**. For example, if the user selects only 5 OOS causes, the size of the set K will be equal to 5 but n will be equal to 10. Another example; if the user selects 25 OOS causes, the size of the set K will be equal to 25 and n will also be equal to 25.

3.7.2 Demonstrative Examples

Assuming that the user selected 13 OOS causes that concern him/her. For the 13 causes, he/she estimates likelihoods P that are shown in Table 3.16 below:

Table 3.16. Demonstrating the OOS Rating Score for a Sample Hypothetical Project.

i (specified by user)	2	5	6	23	25	30	44	56	57	70	74	77	79
Corresponding Cause Code	A2	A5	A6	C2	C4	D1	D15	E6	E7	H4	H8	I3	I5
P (specified by user)	4	2	3	3	2	4	3	4	3	4	5	4	2
L (obtained from Table 3.3)	2.89	2.43	2.29	3.14	2.94	2.56	2.94	2.29	2.24	2.75	2.81	2.79	2.41
I (obtained from Table 3.3)	3.28	2.73	2.49	3.22	3.49	2.93	3.24	2.68	2.93	3.00	3.12	3.15	3.35

Based on the above, the OOS Rating for the user's project is calculated as follows:

$$R_P = \frac{1}{n}\sum_{i \in K} P_i I_i = \frac{1}{13} \times [(4 \times 3.28) + (2 \times 2.73) + \cdots + (2 \times 3.35)] = \mathbf{10.04}$$

The user's project is in Risk Tier #4 because OOS Rating is between 8.225 and 10.075. To calculate the industry's average OOS Rating, the following calculation is undergone (it the same equation used for the OOS Rating of the user with just replacing the user's input of likelihood (P) with the industry's average likelihood (P) obtained from the expert-based survey):

$$R_I = \frac{1}{n}\sum_{i \in K} L_i I_i = \frac{1}{13} \times [(2.89 \times 3.28) + (2.43 \times 2.73) + \cdots + (2.41 \times 3.35)] = \mathbf{8.14}$$

The average industry's OOS Rating for the same selected causes is in Risk Tier #5 because it is between 6.205 and 8.225. Figure 3.10 shows the OOS Rating of the user compared to the industry for the selected causes of OOS. In this project, it seems that the user needs to apply best practices to reach a score lower than the industry's score and transfer his/her project into a safer risk tier (Tier 5 or 6).

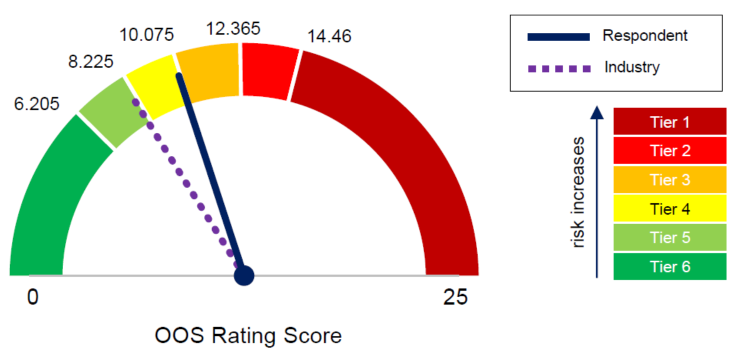


Figure 3.10. The OOS Rating Score for a Sample Hypothetical Project.

3.8 Best Practices for Preventing and Mitigating Out-of-Sequence Work

Through the work of CII Research Team 334, 21 best practices for preventing and mitigating OOS work was developed. Each of these best practices contains the following:

- Detailed actions
- Instructions on when to apply each action (at which project stage)
- Conditions for successful application

- Cost implication
- Targeted outcomes
- An illustrative example of utilizing the best practice

Developing such best practices with their actions was undergone through integrating qualitative and quantitative information from extensive expert-based and project-based surveys conducted by CII RT-334. Statistical correlations were made between different management practices and project attributes in relation to OOS work. The best practices should be beneficial to project participants who wish to prevent OOS work and mitigate its effects in case of its occurrence. As such, the best practices have actions that are suitable for the following four project phases: (1) concept phase; (2) detailed scope phase; (3) detailed design (engineering) phase, and (4) construction phase. Such project phases are defined by the CII as follows:

- <u>Concept Phase:</u> It is the phase where adequate conceptual design is performed to allow selection of the best of identified project approaches, concept(s) is/are analyzed, and a Study Cost Estimate is prepared to confirm project viability. Other deliverables generally include an initial Project Execution Plan, a preliminary schedule and a number of preliminary engineering design documents.

- <u>Detailed Scope Phase:</u> It is the phase where the project objectives, process and design scope definition, major equipment pricing and the Project Execution Plan are finalized to support a Budget Cost Estimate and funding request. Other deliverables include a Detailed Scope Document adequate to effectively support the Detailed Design, Procurement and Construction Phases.

- <u>Detailed Design (Engineering) Phase:</u> It is the phase where multiple discipline design activities take place. The major deliverables from the phase are Issue for Construction (IFC) and Procurement Documents.

- <u>Construction Phase:</u> The phase responsible for the completion of all activities in the project.

Table 3.17 presents the 21 best practices and their mapping with the different categories of OOS causes. The function of this mapping is to determine which of the practices helps in preventing OOS causes related to which of the categories. The mapping was performed, revised, and finalized under the close supervision of the research team's industry panel to ensure optimal practical benefit to the industry. Table 3.18 shows a summary of the 21 best practices, the total number of actions in each best practice, and the project phases suitable for each of those actions.

The actions range from preventive to responsive. Preventive actions help in minimizing the likelihood of OOS work. Responsive actions are those that are performed after the OOS work has already taken place, to mitigate its impacts and prevent them from rippling.

All of the 21 best practices and their detailed actions, along with the other deliverables stated in the beginning of Section 3.8, are written in a 100+ page document that will be published on the CII's website during Summer 2018 under the name "Concept File" in the webpage related to research team #334.

3.9 The OOS Decision Support Tool

An Out-of-Sequence (OOS) Decision Support Tool is developed to summarize all of the research findings (of Chapter 3) and enable industry users to directly benefit from it based on their project conditions in a user-friendly way. The OOS Decision Support Tool will assist project participants in minimizing and mitigating OOS Work. The OOS Decision Support Tool, which is a Microsoft Excel Macro-based software written by Visual Basic, consists of two different modules:

- **Module 1 - Summary Reports:** This module presents the research findings with regards to the causes, early warning signs, and impacts of OOS work. It also presents the overall best practices for preventing and mitigating OOS.

- **Module 2 - Mitigation Tool:** This module calculates the OOS Rating score of the project that the user is investigating. It also provides the detailed best practices for avoiding and mitigating the OOS work in that project depending on the conditions of that project.

Table 3.17. Mapping the Best Practices to the Different Categories of OOS Causes.

	Categories of Causes of Out-of-Sequence Work										
21 Best Practices	Project Team (A)	Planning (B)	Engineering (C)	Execution (D)	Material Management (E)	Quality Management (F)	Safety Management (G)	Resource Management (H)	Change Management (I)	Commissioning (J)	Legal/Commercial Aspects (K)
Enhancing Coordination between Project Parties	●	●									●
Increasing Construction Involvement in Design		●	●	●						●	
Minimizing Negative impacts of Schedule Compression		●		●	●		●	●	●		●
Reducing Excessive Absenteeism and Turnover	●	●		●			●	●			●
Minimizing and Integrating Changes			●	●					●		
Schedule Updating and Lookahead planning		●	●	●							
Managing the RFI Process		●	●	●				●	●		
Optimizing Material Management Plan and Process		●	●		●						
Reacting to Out-of-Sequence Work (OOS)	●	●		●	●			●	●		●
Using Lean Construction Principles to Minimize OOS		●	●	●	●	●		●			
Using an Experienced Team	●										
Using the Proper Project Delivery System	●	●									●
Increasing Owner's Participation during Construction	●	●		●						●	
Increasing Engineering Support to Construction	●	●	●	●							
Having the Right Level of Detail in the Schedule before Mobilization for Construction	●	●									
Forming the Construction Workforce from Skilled Labor		●		●		●	●	●			
Minimizing the Number of Drawing Revisions			●	●		●			●	●	
Integrating OOS as part of the Risk Management Plan		●									●
Optimizing the use of Information Technology		●	●	●							
Implementing Effective Planning for Startup		●	●	●						●	
Having a Comprehensive Project Execution Plan	●	●	●	●	●	●	●	●	●	●	●

Table 3.18. Mapping the Best Practices to the Different Project Phases.

21 Best Practices	Total No. of Actions	No. of Actions to be Taken at these Project Stages			
		Concept	Detailed Scope	Detailed Design	Construction
Enhancing Coordination between Project Parties	15	5	13	12	12
Increasing Construction Involvement in Design	4	2	3	4	4
Minimizing Negative impacts of Schedule Compression	3	0	0	3	3
Reducing Excessive Absenteeism and Turnover	8	0	2	2	8
Minimizing and Integrating Changes	13	3	10	10	8
Schedule Updating and Lookahead planning	6	0	1	4	6
Managing the RFI Process	6	0	1	4	6
Optimizing Material Management Plan and Process	12	1	4	8	9
Reacting to Out-of-Sequence Work (OOS)	8	0	0	0	8
Using Lean Construction Principles to Minimize OOS	9	1	2	5	6
Using an Experienced Team	5	4	3	3	4
Using the Proper Project Delivery System	2	2	0	0	0
Increasing Owner's Participation during Construction	7	7	7	7	7
Increasing Engineering Support to Construction	4	0	1	3	3
Having the Right Level of Detail in the Schedule before Mobilization for Construction	7	0	7	6	3
Forming the Construction Workforce from Skilled Labor	13	0	0	0	13
Minimizing the Number of Drawing Revisions	7	0	3	6	3
Integrating OOS as part of the Risk Management Plan	6	4	6	3	3
Optimizing the use of Information Technology	7	5	6	5	6
Implementing Effective Planning for Startup	7	0	6	7	3
Having a Comprehensive Project Execution Plan	15	2	14	12	9
Total Number of Actions →	164	36	89	104	124

Table 3.19 lists in detail the functions that are performed by the different modules of the OOS Decision Support Tool. The OOS Decision Support Tool is best used by a project participant if he/she is involved in a construction project at the FEL2, FEL3, Design, or Construction phase and would like to:

- See the causes and early warning signs that lead to OOS, and/or
- Calculate the OOS Rating Score for your project and compare your project's OOS risk to the industry's score, and/or
- Know what actions to take (best practices) to avoid OOS (if you are at FEL2, FEL3, or Design) or mitigate OOS (if you are at the construction phase), and/or
- See summary reports on how OOS is manifested in the industry according to the findings of the research.

Table 3.19. Functions and Capabilities of the OOS Decision Support Tool

Capabilities	Module 1: Summary Reports	Module 2: Mitigation Tool
Present the 88 causes of OOS and their corresponding likelihood of occurrence, relative impact, and risk rating.	●	●
Present a comparison between owners and contractors with regards to the likelihood of occurrence and relative impact of the 88 causes of OOS.	●	●
Present the 54 early warning signs of OOS and their corresponding correlation with OOS.	●	
Present a comparison between owners and contractors with regards to the correlation rating of the OOS early warning signs.	●	
Present statistical correlations between the different causes, early warning signs, and best practices of OOS; and different project parameters.	●	
Present 21 best practices for preventing/mitigating OOS as well including information on actions, when to apply, conditions for successful application, targeted outcomes (supported with statistics), cautions, and illustrative examples.	●	
Calculate the OOS Rating Score for the user's project and compare it to the industry's average.		●
Determine the risk tier of the project.		●
Produce detailed best practices for preventing/mitigating OOS in the user's project based on the user's input and project stage.		●

Figure 3.11 provides guidelines on how to get the maximum benefit from using the OOS Decision Support Tool. The guidelines are in the form of a sequence that should be followed.

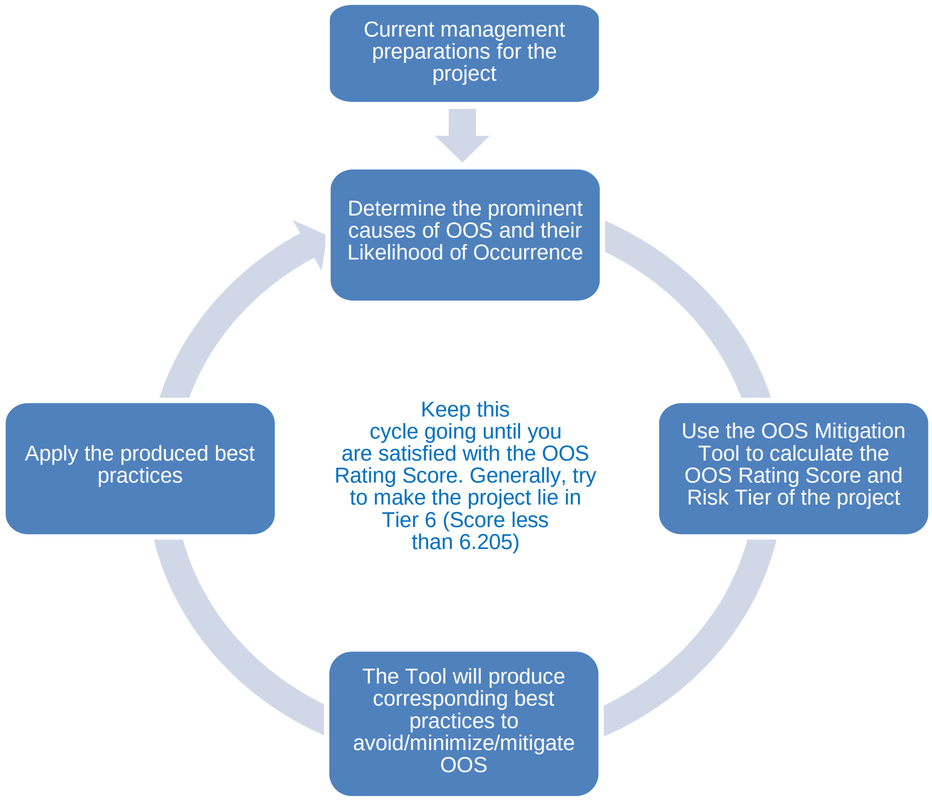


Figure 3.11. Getting the Maximum benefit from using the OOS Decision Support Tool

3.9.1 Downloading and Using the OOS Decision Support Tool

The OOS Decision Support Tool can be downloaded from the following link: https://goo.gl/dApxFL

*The document named "A User's Guide to the Out-of-Sequence (OOS) Decision Support Tool" in the **Appendix C** provides detailed steps on how to use the OOS Decision Support Tool*.

3.9.2 The User Interface of the OOS Decision Support Tool

Figures 3.12 and 3.13 provide sample screenshots of the use and outcomes of the tool.

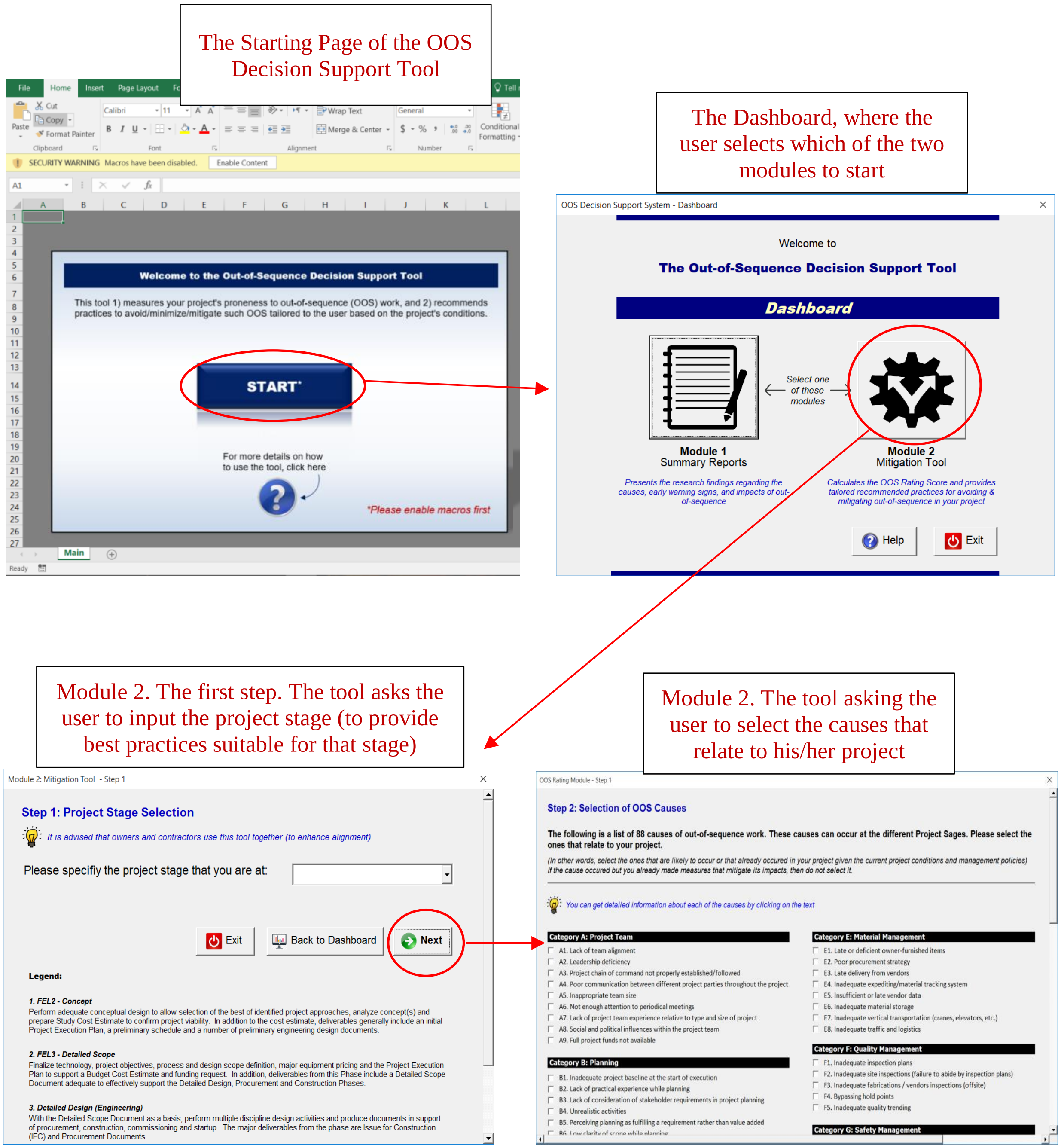


Figure 3.12. Screenshot of the OOS Decision Support Tool.

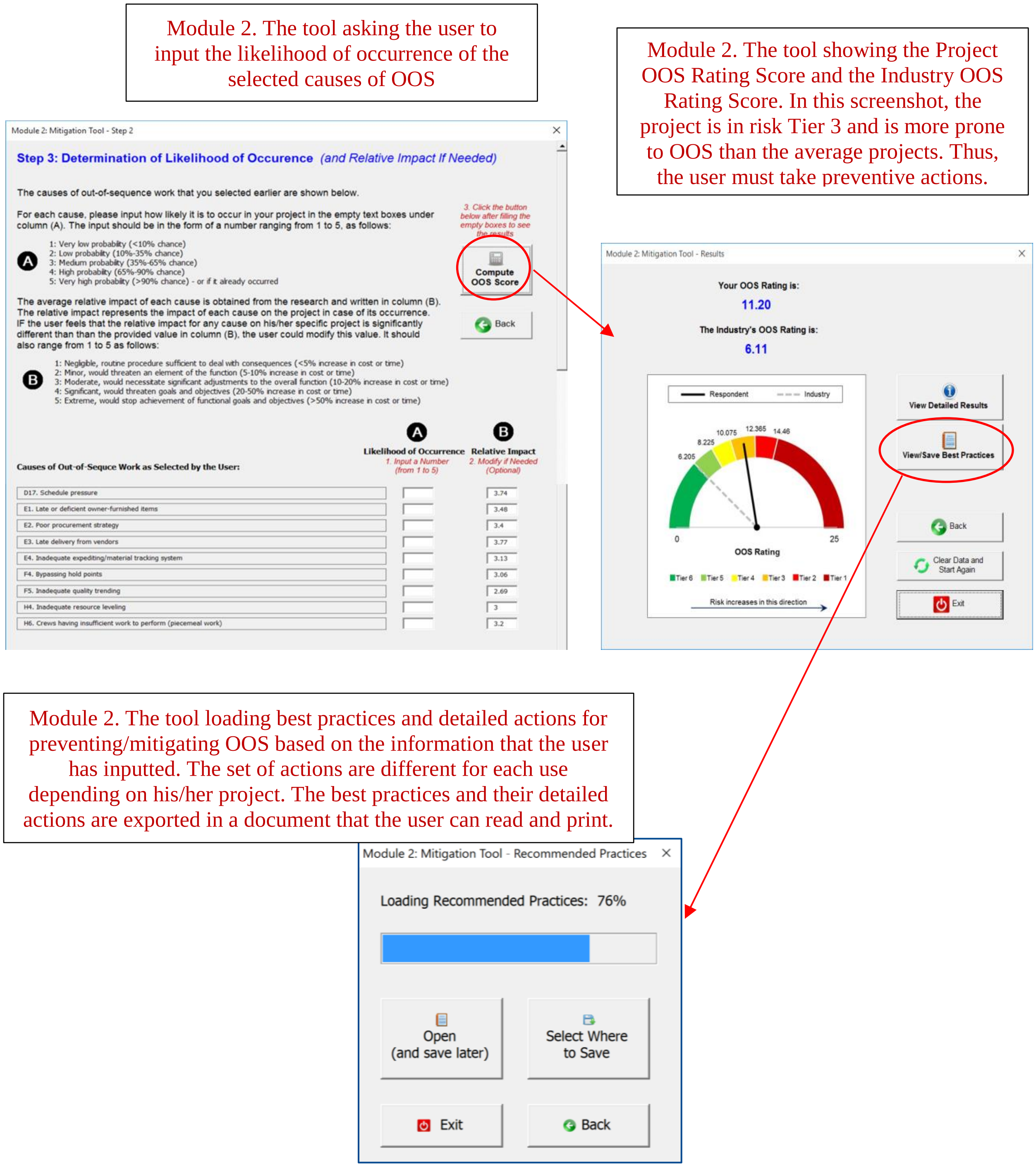


Figure 3.13. Screenshot of the OOS Decision Support Tool (Continued).

3.9.3 Applicability and Validation of the OOS Decision Support Tool

The tool underwent several modifications based on pilot tests and discussions with the industry panel to ensure ease of use and practicality before reaching its final form. The final form of the tool has been used in 11 construction projects, 9 of them are ongoing and 2 are completed. The users who used the tool in their projects were surveyed after using it. The results indicated that the tool is in fact beneficial to the industry and ready as an off-the-shelf product. The users confirmed that the OOS decision Support Tool helped them in analyzing their projects and proposed case-based helpful actions for preventing OOS work; thus, saving money and time in their projects. In fact, all of the users saw benefits from using Module 2 of the tool and 92% of them saw benefits from using Module 1. Finally, 100% of the surveyed users plan to use the tool on future projects.

Additional statistics regarding the 11 projects that used the tool include the following:

- In 10 out of the 11 projects, the respondents confirmed that the tool is user-friendly.
- In 100% of the projects that used the tool, the respondents indicated that the user manual is clear in reporting the instructions on what to do.
- The respondents found the output reporting of the best practices that are generated by the tool for their projects:
    - Extremely useful (1 respondent)
    - Very useful (6 respondents)
    - Moderately useful (3 respondents)
    - Slightly useful (1 respondent)
    - Not at all useful (no respondent)

3.10 Outcomes and How They Relate to Dispute Mitigation

This research chapter addresses a persistent missing piece in the construction management body of knowledge as it is the first research endeavor to investigate OOS work as a stand-alone project impactor. It identified the causes of OOS and quantified their likelihood of occurrence and relative impacts. Also, it identified the early warning signs and determined their correlation to OOS. As such, when such causes and early warning signs take place in projects, the stakeholders would recognize them and take actions to prevent their repercussions. Moreover, the chapter provides the stakeholders with such actions (also called best practices) in a user-friendly decision support tool. Such minimization of OOS work and mitigation of its impacts will reduce the relevant disputes and enhance the workflow of projects; thus, saving time and money. Furthermore, the chapter compared between owners and contractors to examine the difference in their perception of OOS work. Highlighting these differences provides “heads-up” to promote alignment and enhanced communication between owners and contractors for healthier project environments.

3.11 Recommendations for Future Work

We see the proper step moving forward is quantifying how the OOS Rating Score is related to the different project performance indicators (such as the cost performance index CPI and the schedule performance index SPI). This will enable answering the question of “if my project has an OOS Rating Score of 13.5, what is the forecasted increase in project cost and schedule?”. For this, we recommend having several projects using the developed OOS Decision Support Tool and map the outputted OOS Rating Score to the different project key performance indicators. When this data is collected, regressions models could be developed to forecast the overruns of any project given its OOS Rating Score that is obtained from the project’s managerial conditions. This will strengthen the applicability of the OOS Rating Score and will make it more informative. The score is now helpful in comparing the project’s OOS risk proneness to the industry average given the same conditions. Also, it is helpful is specifying the risk tier of the project so that stakeholders would make preemptive actions if they are in a tier with high OOS risks. However, adding the quantitative capabilities of forecasting the project performance would be a significant contribution to the body of knowledge. Another recommended future work would be finding correlations between early warning signs and causes of OOS for more rigorous analysis. One more direction could be finding ways of using BIM to provide objective and quantifiable inputs to the OOS Decision Support Tool to calculate the OOS Rating Score rather than the user’s inputs that might seem subjective.

3.12 Related Appendices

Appendix B presents the questions of the expert-based survey. Appendix C presents the guiding manual for using the OOS Decision Support Tool. Appendix D presents the used Visual Basic (VBA) Code in developing the different modules of the OOS Decision Support Tool.

CHAPTER 4:
SYSTEM DYNAMICS (SD) MODELING OF OUT-OF-SEQUENCE WORK

4.1 Overview

Construction projects are <u>complex</u> in the sense that they are composed of multiple inter-related feedback systems that impact one another, and <u>dynamic</u> in the sense that the states of these systems are always changing (Taylor and Ford 2008, Lyneis et al. 2001). For example, project changes that appear to be minor lead to rippled disruptions to the work flow; such rippled impacts could occur as soon as the change takes place or later in the project (Cooper and Lee 2009). Construction projects almost never go as planned. In fact, changes are the norm rather than the exception in the construction field (Sterman 1992). These changes could be caused by internal circumstances such as changes in designs, specifications, time of completion, and financing arrangements; or external circumstances not within the parties' control such as weather, market, and political conditions. How the parties react to change is what governs whether such change will negatively impact the project in terms of productivity, delays, quality, cost overruns or not. Moreover, due to the complexity of construction projects, responses to work environment and managerial decisions are highly unpredictable (Love et al. 2002).

Over the years, traditional analytical project management and scheduling methodologies such as the critical path method and delay analysis have been used extensively for estimating the impacts of changes on project durations and costs. They also have been used for dispute resolution after projects have been executed to allocate the responsibilities for changes and distribute the associated added costs on the parties. Despite their wide use, such methodologies fall short in grasping the full rippled and indirect impacts of changes due to the over-simplifications made by their inherent empirical and simple analytical nature (Rodrigues and Williams 1998). These models never really show how parties are affected; for example, they might over-estimate or under-estimate the time and cost impacts of changes or managerial actions. To demonstrate, consider an example of changing a design specification leading to an increase in the time required to finish a set of design drawings. In the CPM approach, the new time of completing the drawings would be added to the schedule and the time and cost impacts would be calculated under the implicit assumption that the durations of all other activities are unaffected. This assumption ignores all other interactions, leading to underestimation of impacts. The interactions in this case would be, for example, the change in the specification requires the hiring and training of new engineers. So, skilled engineers are diverted from work to training the new engineers. Trainees may generate more errors thus increasing rework rate. At that time, some construction work may have taken place without complete designs, leading to more errors and rework (Sterman 2000). Such accumulated effects deem the project to suffer various impacts that cannot be foreseen by traditional methods.

Realizing the limited abilities of traditional analytical techniques, companies and researchers are now turning to system dynamics (SD) models as “complementary” means to the traditional models (Cooper et al. 2002). System dynamics (SD) is a computer modeling technique focused on understanding the behavior of complex systems over time (Sterman 2000). SD aspires to understanding and improvement of systems throughout simulating the complexities, non-linearities, and feedback loop structures that are inherent in the real-world processes (Forrester 1994).

Sterman (1992) and Chang et al. (1991) provide philosophical and practical arguments to support the use of SD in the construction management process. SD is known for its ability to efficiently simulate and analyze systems with certain characteristics; which are exactly similar to the characteristics of construction projects (Ogunlana et al. 2003). In short, construction projects are: (1) *highly complex* because they involve simultaneous activities and inter-dependent processes; (2) *dynamic* in which almost all components - such as the utilized man-hours - change over time; (3) *contain several interconnected feedbacks processes* (for example the amount and experience of workforce impacts the progress; which in turn determines the needed workforce for the future time step and so on); (4) *involve non-linear relationships* (for example production rate does not increase linearly by increasing the number of working hours per day), and (5) *contain both quantitative and qualitative information* such as the percentage of unapproved work and the level of trust between parties respectively. SD is specialized in tackling problems that have the above-mentioned features.

For that, SD is highly applicable in construction project management in two folds. The first fold is that is helps in understanding the dynamics of complex processes in a way that is not understandable by other means. For example, Love et al. (1999) used SD to study the causes of rework in construction and how certain actions that seem to be beneficial actually might lead to more rework and delays. The second fold is that dynamic models could be developed for advanced project monitoring and control, rework analysis, human resource management, and dispute resolution (Weil and Etherton 1990, Rodrigues and Bowers 1996).

The use of SD in the industry has been increasing (especially in the aerospace, automotive, civil construction, and energy fields) due to its capabilities of grasping complex project interconnectivities. Lyneis and Ford (2007) counted more than 50 companies that have been using SD for hundreds of projects in applications such as project management, disputes analysis, post-project evaluation, project estimating, risk assessment, project control, and management training and education. Such companies have a classic model structure and make modifications to that structure in each project to suit its needs.

The following sections detail: (1) the steps of meta-analysis that was conducted on the available SD literature; (2) the knowledge gaps that need to be addressed (the major knowledge gap turned to be the lack of SD models studying out-of-sequence work), and (3) the steps and result of developing an advanced SD model for studying out-of-sequence work (which covers the major knowledge gap).

4.2 Background Information about System Dynamics

Since its inception by Professor Jay Forrester in 1950s at Massachusetts Institute of Technology (MIT), system dynamics has gained a wide popularity and has been applied to address a variety of management, social, economic, political, industrial, engineering, environmental, and other research areas around the world. To list a few recent examples, system dynamics was used to study the water dynamics in dam reservoirs (Kieth et al. 2017), medical admission avoidance (Walsh et al. 2015), electricity pricing mechanisms (Tziogas et al. 2017), agro-ecological sustainability (Nabavi et al. 2017), and public policy in urban planning and social welfare (Ghaffarzadegan et al. 2011). In construction research, system dynamics has been used to study the dynamics of different project and industry-related related aspects such as rework (Love et al. 2010, Li et al.

2014), construction firm performance (Tang and Ogunlana 2003), tipping point dynamics (Taylor and Ford 2008), and contingency management (Ford 2002).

In system dynamics, a "system" is defined as a collection of elements that function together as a unit for a defined purpose. A "dynamic" system is one in which the components act together to produce changes over time. These dynamics are determined by cause and effect relationships among components that result in "feedback". In fact, the first step in developing a system dynamics model after defining the scope and the key variables is plotting an arrow diagram on which variables are connected with one another with arrows. These arrows represent causal relationship. As such, the variable at the arrow tail causes a change in the variable at the arrowhead. This change or effect could be linear or non-linear, instant or delayed, and deterministic or stochastic. System dynamics has the ability to incorporate these types of relationships. After that, the formed arrow diagram - also referred to as the causal loop diagram – is further developed into a stock-and-flow diagram with mathematical formulations representing the different causal links – i.e. arrows. This diagram is formed of stocks, flows, and variables all connected by causal arrows; where there is an actual mathematical equation behind each arrow. A stock is the integral of the net flow added to the initial value of the stock (Equation 4.1).

$$Stock(t) = \int_{t_0}^{t} [Inflow(s) - Outflow(s)]ds + Stock(t_0) \qquad \text{Eq. (4.1)}$$

The building blocks of any SD model are Levels, Rates, Auxiliary Variables, Data Variable, and Constants. The Levels are state variables that define the dynamics of a system. More formally, the following equations show the basic mathematical form of SD models. The <u>level</u> variables describe the current state or condition of the system. They represent the stocks. The <u>rate</u> variables represent the dynamic changes in the system over a specific period. They serve as inputs and outputs of the level variables. The <u>auxiliary</u> variables are those computed from other variables at a given time. Auxiliaries are typically the most numerous variable type, and an auxiliary variable has an expression involving other variables in its equation. <u>Data</u> variables represent the exogenous conditions; meaning that they hold values that change over time but are independent of anything that happens to other variables. Finally, <u>constant</u> variables are those whose values do not change over time. A constant can be temporarily changed prior to simulating a model. The four types of variables are connected through arrows indicating that there is either substance or information flow between the two variables concerned. The formal mathematical representation of the variable types is as follows:

$$L_t = \int_0^T R_t \, dt \qquad or \qquad \frac{d}{dt} L_t = R_t \qquad \text{Eq. (4.2)}$$

$$R_t = g(L_t, A_t, D_t, C) \qquad \text{Eq. (4.3)}$$

$$A_t = f(L_t, A_t, D_t, C) \qquad \text{Eq. (4.4)}$$

$$L_0 = h(L_0, A_0, D_0, C) \qquad \text{Eq. (4.5)}$$

Where, L represents levels, R represents rates, A represents auxiliary variables, D represents data variables, and C represents constants.

Equation 4.2 represents the evolution of the system over time. Equation 4.3 represents the computation of the rates determining that evolution. Equation 4.4 represents the intermediate results necessary to compute the rates. Finally, Equation 4.5 represents the initialization of the system. In these equations g, h, and f are arbitrary, nonlinear, potentially time varying, vector-valued functions. They can also include conditionals, stochastics, and other advanced forms.

Having this ability to simulate interconnected feedbacks, system dynamics allows users to trace out the behavior of the system over time and to analyze how structural changes in one part of a system might affect the behavior of the system as a whole. This also enables it to isolate each change or managerial policy and obtain its direct and indirect impacts quantitatively throughout its capability of capturing complex causal interdependences. Accordingly, system dynamics allows modelers to quantitatively assess the benefits and losses of various angles in projects, both retrospectively and prospectively (Sterman 2000). Firstly, in the retrospective viewpoint, in construction management for example, it enables effective assessment of the magnitude and sources of cost and schedule overruns (Cooper and Lee 2009). This property has helped in dispute mitigation; where system dynamics played a role in resolving construction and business disputes through identifying the rippled impacts of the parties' actions and allocating the corresponding damages fairly to those parties (Weil and Etherton 1990). Secondly, in the prospective viewpoint; utilizing system dynamics in the project control stage enables conducting what-if-analyses and calculating the direct as well as rippled impacts of any policy or change. By doing so, project teams would be able to "see what the future looks like" at different scenarios so they would be prepared for that future, or even change it (Boateng et al. 2013). In summary, SD models can answer the following questions (Weil and Dalton 1992):

- ***Why*** did certain problems occur?
- What ***would have*** happened without certain events or conditions?
- What ***will*** performance be under a specified set of circumstances?
- ***What if*** management took this action?

The following example illustrates in simple terms the advantage of using system dynamics. In an engineering activity, if the manager wants to shorten the duration of such activity by half, traditional calculations would suggest that he/she doubles the number of engineers. This is a very simple abstraction that is only true in rare occasions. However, in reality, there are different associated feedbacks related to hiring. For example, if the newly hired engineers are not experienced, their probability of making mistakes that lead to design rework is higher than that of others. Also, by hiring new engineers, some of the old engineers would focus some of their attention towards orienting and training the new engineers; thus, neither the old or the new ones would be working with full efficiency, at least at the beginning. As such, the overall productivity is not just a simply multiplication of the productivity of one engineer and the total number of engineers. SD is able to grasp these feedbacks and provide the overall behavior of the system over time.

To clarify, dynamic models are not replacements of traditional models. The strength of traditional models lies within their individualistic view of project activities and how they are related. They are excellent in directing construction teams to when and where to perform and in estimating costs and durations at optimal conditions. On another fold, dynamic models are powerful in grasping the different interconnected feedbacks that play roles in the overall project progress holistically. Accordingly, dynamic models are more effective in estimating the impacts of change and the influences of different managerial policies within the project. "*System dynamics* *models assume a high-level view of the whole project management process, focusing on human factors and managerial policies. They have an inherent flexibility which enables them to incorporate a wide range of influences specific to applications. The models used in the traditional focus on the project work structure and are more specialised, assuming a detailed view of the individual parts of the project management process. The traditional techniques are more rigid, enforcing a particular view of the project; this can ease their implementation but at the expense of some reality: while ensuring rigorous monitoring of the project past, their view of the future is focused on a "planned success". In contrast, system dynamics simulation models provide a laboratory to test several different scenarios for the project, delivering a clearer and perhaps more realistic view of the possible futures*" (Rodrigues and Bowers 1995). Table 4.1, which is abstracted from Alzraiee et al (2015) and Boateng et al (2013), demonstrates the applicability of system dynamics in construction projects as related to the critical path method.

Table 4.1. Comparison between the Critical Path Method and System Dynamics.

Perspective	Critical Path Method	System Dynamics
Behavior	Linear	Linear and non-linear
Data type	Quantitative	Quantitative and Qualitative
Capturing managerial corrective actions	Low	Very high
Realistic for project acceleration	Low	Very high
Level of Detail and Focus	Activity	Holistic and feedbacks
Risks and uncertainty management	High	Very high
Evaluating impacts of uncertainty	High	Very high
Evaluating decision level	High	Very high
Estimating accurate project cost, duration and resources	High	Very high
Work schedule	High	Very high
Project control and monitoring	Yes	Yes
Showing interrelationships	Yes	Yes
Accounting for feedback effects	Yes (Low)	Very High
Work specification	Yes	No
Handling multi interdependent components	No	Yes
Productivity impact consideration	No	Yes
Handling multiple feedback processes	No	Yes
Handling non-linear relationships	No	Yes
Computational capability for predictions	No	Yes

To this end, SD has been used to study the impact of rework on the performance of construction (Love et al. 1999, 2000a, 2000b, 2002, 2010; Cooper 1993, 1994); impact of design rework on the design and construction stages (Park and Pena-Mora 2003; Lee et al. 2005; Li et al. 2014); tipping point dynamics (Taylor and Ford 2006, 2008); construction firm performance (Tang and Ogunlana 2003; Ogunlana et al. 2003); Planning and failures in fast-track implementation (Ford and Sterman 1998, 2003a; Peña-Mora and Li 2001; Peña-Mora and Park 2001); management of project contingencies (Ford 2002); construction innovation (Park et al. 2004); change management (Lee et al. 2005, 2006; Park and Pena-Mora 2003); concealing rework requirements (Ford and Sterman 2003b); infrastructure rehabilitation (Rashedi and Hegazy 2015); safety in the construction site (Jiang et al. 2014); risk effects on schedule delays (Wang and Yuan 2016); effect of working hours on performance (Alvanchi et al. 2011); sustainability considerations in highway projects (Ozcan-Deniz and Zhu 2016); concession period in build-operate-transfer (BOT) projects (Khanzadi et al. 2012); and impact of public policy and societal risk perception on nuclear power plant construction (Taylor et al. 2012). However, it has not been used to study OOS work and its corresponding dynamics.

4.3 Current State of the System Dynamic Literature in Construction Management Applications

At first sight, it might seem that researchers have covered all important angles of construction management from a dynamic perspective (i.e. used SD to model and analyze all significant aspects of project management). However, a thorough and quantitative investigation of the literature has proven otherwise. There still exist multiple major gaps in the application of SD in construction management. Due to the large number of academic publications, and the exaggerations made by some of the authors on the capabilities of their developed models, identifying the knowledge gaps is not a simple endeavor. As such, a meta-analysis of the literature was conducted to identify such knowledge gaps and direct future researchers towards them.

The following steps were taken to identify the knowledge gaps:

1. All relevant academic publications were collected. The relevancy was determined based on the following criteria:

    - Peer-reviewed and published in journals;

- Related directly to construction projects (some of the papers that were focused on product development projects were included as their topics and models were very closely related to managing construction projects), and

- Discussed the evolving dynamics of construction processes using system dynamics; by either developing models or just proposing the use of system dynamic in construction project management.

2. The key dynamic parameters that impact the progress of any construction project are identified and defined (Section 4.3.1).

3. Social network analysis (SNA) is used to: (1) further investigate the relationships and the use of all the identified parameters in previous studies, and (2) pinpoint the dynamic parameters that need further research (gaps in the literature).

4.3.1 Identifying Dynamic Parameters for Managing Construction Projects

A distinction should be made between what is referred to as project "*parameters*" in this chapter and project "*risks*". On one hand, parameters are those factors that directly impact, control, and define the project progress, in terms of schedule, cost, quality, productivity…etc. Also, in some sense, parameters could be controlled by the project parties. So, if we imagine that the construction project is an airplane, the parameters are the dials that are controlled by the pilot to steer the airplane and control its direction, velocity…etc. In that same analogy, the parameters are also the engines and electric systems that are affected by the dials and give feedback. For example, in construction projects, the overtime is a parameter that is often used by the project manager to speed up the project. Moreover, parameters are all inter-related. So, making a change in one parameter might affect the others; making the cause-effect relationship between the parameter and progress non-linear and un-calculable using the simple scheduling techniques. For example, it is true that using overtime increases productivity; but the use of overtime for prolonged durations will cause fatigue – which is another parameter - and in turn, reduce the productivity instead.

On the other hand, the term "risks" in this paper refers to those factors that have a direct impact on the project parameters, and hence affect the project progress indirectly. In the airplane analogy, risks would be aspects that affect the airplane and not directly under the control of the pilot such as wind direction and total weight of the passengers. However, the pilot has the ability to react to those "risks" by manipulating the "parameters" to arrive safely and on time. An example in construction, late project payment is a risk that has impacts on several project parameters such as productivity, resource utilization, and re-sequencing. These parameters in turn impact the project progress.

Figure 4.1 shows the simplified relationship between what are referred to as risks, parameters, and progress in this chapter. Project managers can take measures to control how the project parameters would react in the case of occurrence of risks. Also, the parameters themselves, if not controlled appropriately, can increase the severity of the risks or even create new risks. As such, even if a project manager was able to eliminate all major risks, he/she still has to effectively control the parameters to finish the project within the approved budget and schedule.

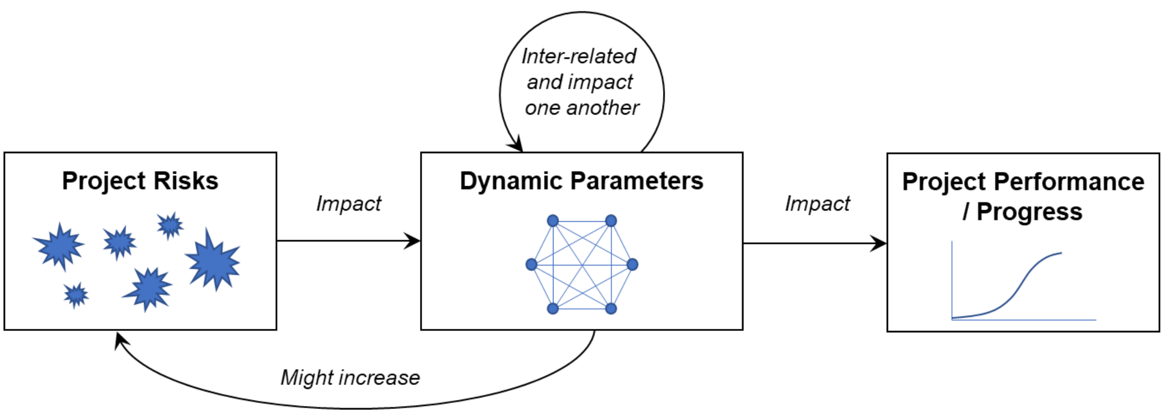


Figure 4.1. Causal Relationship among Risks, Parameter, and Performance.

Over the years, researchers have well-studied risks associated with construction performance. Previous research has combined the risks and parameters and obtained relationships between them and project performance. Most of such comprehensive research efforts only considered simple linear relationships between the risks, their probabilities, and their impacts on cost and schedule without taking into consideration their interdependencies. This research makes the distinction between risks and parameters as explained earlier. Recently, more research efforts have become oriented towards studying the dynamics of the project parameters; thus, adding more rigor to understanding the interrelationships of the different project feedbacks for enhanced project management and control. These research efforts are the ones included in the meta-analysis as shown in Table 4.2.

Table 4.2. Studies Included in the Meta-Analysis.

Used Sources in the Meta-Analysis			
Huot and Sylvestre (1985)	Howick and Eden (2001)	Park and Pena-Mora (2004)	Taylor and Ford (2008)
Homer et al. (1993)	Lyneis et al. (2001)	Park et al. (2004)	Rahmandad and Hu (2010)
Rodrigues and Bowers (1995)	Pena-Mora and Li (2001)	Howick (2005)	Han et al. (2011)
Williams et al. (1995a)	Pena-Mora and Park (2001)	Lee et al. (2005)	Love et al. (2011)
Williams et al. (1995b)	Williams et al. (2001)	Bayer and Gann (2006)	Alvanchi et al. (2012)
Rodrigues and Williams (1998)	Cooper et al. (2002)	Ford and Bhargav (2006)	Boateng et al. (2013)
Hsia et al. (1999)	Ford (2002)	Lee et al. (2006a)	Wan et al. (2013)
Love et al. (1999)	Love et al. (2002)	Lee et al. (2006b)	Li and Taylor (2014)
Reichelt and Lyneis (1999)	Ford and Sterman (2003a)	Lee et al. (2006c)	Alzraiee (2015)
Williams (1999)	Ford and Sterman (2003b)	Motawa et al. (2006)	De Marco et al. (2015)
Graham (2000)	Howick (2003)	Nepal et al. (2006)	Love et al (2016)
Love et al. (2000)	Park and Pena-Mora (2003)	Taylor and Ford (2006)	Wang and Yuan (2017)
Williams (2000)	Ford et al. (2004)	Lyneis and Ford (2007)	Leon et al. (2018)
Eden et al. (2000)	Park (2004)	Pena-Mora and Li (2008)	

By analyzing the studies in Table 4.2, the author was able to identify 25 dynamic parameters that control the project performance. Table 4.3 shows the identified parameters and their meaning in the context of this research. It should be noted that aspects related to safety, environmental compliance, and sustainability are not in the scope of this research. It should be noted that what is referred to as “parameters” in Table 4.3 is actually *categories of parameters* rather than singular parameters. For example, parameter “P2: Schedule Pressure” covers several sub-parameters such as hiring new staff, using overtime, and adding shifts. The table provides examples on what is covered in each parameter. As such, the list in the table covers all major sub-parameters that have an impact on project performance.

Table 4.3. Identified Key Project Dynamic Parameters.

Code	Dynamic Parameter	Explanation in the Context of this Paper
P1.	Realistic Scheduling:	This term includes several elements such as recognizing and incorporating uncertainties in duration estimation, adding contingency buffer to activities, and determining proper logical sequencing of activities. This is at the planning stage. The term also includes having realistic schedule relaxation response to changes and disruptions during execution.
P2.	Schedule Pressure:	This action is taken when the project is behind schedule, or when the project is on schedule but needs to be accelerated. This requires assessing the progress of the project compared to the planned progress, and taking the appropriate pressure action, such as hiring new staff, using overtime, or adding shifts.
P3.	Complexity:	Includes the level of activity interdependencies, overlapping, and complexity (skill level required to execute them). It also includes the level of concurrency between engineering and execution.
P4.	Coordination and Communication:	Includes client progress-reporting demands, progress meetings, and coordination and communication between the owner, engineer, and contractor. Also includes the level of understanding among parties through continuous review of the system definition and its required functionality. Moreover, it includes any disconnects in BIM between the general contractor and the subcontractors.
P5.	Efficiency of the Approval Process:	The time taken by the engineer or the owner to approve changes, reply to request for information (RFIs), or reply to the contractor' queries/requests in general. This also covers the attitude of the owner/engineer towards the contractor. For example, some replies are meant to be unclear just for the sake of stretching time.
P6.	Trust and Motivation:	Mutual trust between the parties and within the parties internally. For example, trust of the contractor that the owner will pay on time, trust of the owner that the contractor will deliver, and trust of the workers/engineers that their overtime is awarded. This also includes incentives to increase the motivation of the staff.
P7.	Ripple Effects of Schedule Pressure:	Prolonged working hours (i.e. overtime) increase fatigue and cause decline in morale. This leads to reduced productivity and increased errors. This also has an impact on the activity sequencing.
P8.	Productivity of Workforce:	Which is the units of work executed per unit of man-hour. This is impacted by several factors such as overtime, fatigue, level of activity complexity, motivation, and technology.
P9.	Constructability Reviews:	Having the contractor involved in the design stage to ensure that the designed works are constructible with minimal interruptions and costs related to the construction method. It also includes having the end-users involved in reviewing and revising project specifications early on. This minimizes unplanned delays and workflow discontinuity.
P10.	Resource Development:	This term refers to the experience and reliability of the staff that is allocated or hired in the project. It also refers to the training that the staff is taking in case they are not experienced.
P11.	Resource Allocation:	Refers to the allocation of the available human resources on the tasks in hand; either engineering or execution tasks. It also refers to the ability of accurately determining the needed human resources based on the project's performance and the time remaining.
P12.	Absenteeism and Turnover:	This term is self-explanatory. The rate of absenteeism and turnover in a construction project impacts labor cost and productivity.
P13.	Workplace Congestion:	Using more resources than required impacts productivity. This could be the overmanning effect, which steps from increasing the crew size over the optimum size; or the over-crowding effect, which is having too many different crews to work at the same area
P14.	Overtime and Added Shifts:	These are two different polices that are usually made by project managers to make up for delayed progress or to speed up work.

Table 4.3. Continued. Identified Key Project Dynamic Parameters.

Code	Dynamic Parameter	Explanation in the Context of this Paper
P15.	Technology:	This refers to the technology in engineering, execution, or management. Examples of engineering technology include the use of 3D modeling and Building Information Modeling (BIM). Examples of execution technology include modern construction equipment and automated construction methods. Examples of management technology include the use of electronic integrated management systems. Relevant disconnects in BIM between contractor and subcontractors are part of P4.
P16.	Rework in Execution:	This refers to the mistakes that are discovered during execution that need to be reworked. It also refers to any rework that is made due to intended changes in design, not necessarily due to mistakes.
P17.	Rework in Design:	This refers to mistakes in designs that require producing new drawings for already-made designs. It also includes rework in drawings that are due to intended changes in design.
P18.	Reliability of Quality Assurance Staff:	Includes the time taken by the QA staff to check and approve executed works. It also includes their reliability in terms of the percentage of falsely approving erroneous works that are discovered later in the project.
P19.	Out-of-Sequence Work:	Refers to the work that is performed out of its intended logical sequence, either in terms of number of activities or cost of such activities. This is measurable using scheduling software that is used by almost all contractors.
P20.	Controlled Change:	Changes made intentionally by the parties such as change orders, variations, changes in construction sequence. These could be made as a reaction to the project's delayed progress or could be made regardless of the progress.
P21.	Uncontrolled Change:	Change made as a reaction to external risks such as weather conditions, unforeseen site conditions, and market fluctuations.
P22.	Fabrication Quality:	This includes the errors in the fabricated items and the quality approval of such items.
P23.	Communication with Fabricators:	This includes the ordering time, delivery time, and other aspects of communication with vendors and fabricators.
P24.	Financial Estimating:	Includes the ability to estimate cost of change and the earned value at any point in time. It also includes considering financial limitations when it comes to managerial decisions such as increasing staff.
P25.	Budget Contingency:	Having contingency accounts and maneuvering through the project costs within such budget contingencies. This is tied to the financial estimating parameter and other ones such as the controlled and uncontrolled changes.

4.3.2 Mathematical Analysis and Social Network Analysis (SNA) for Identifying the Knowledge Gaps

Each of the studied papers of the literature had one of the following characteristics with regards to the 25 dynamic parameters:

Type 1: Papers of this type provided theoretical discussion on the dynamics of some of the parameters and how understanding these parameters would benefit the construction project management. Such papers provided causal loop diagrams clarifying such dynamics without providing actual mathematical models. This theoretical discussion is denoted by the letter "*M*" in this research. An example of type 1 is the work of Boateng et al (2013).

Type 2: Papers of this type provided both theoretical discussion (similar to type 1) as well as mathematical models utilizing SD in tackling the associated research problems. Provision of the mathematical models is denoted by the letter "*S*" in this research. The work of Alvanchi et al. (2012) is an example of type 2; where it discussed the dynamics of work-hours and their impacts on productivity, and developed a system dynanmics model to simulate such dynamics. So, this type has both M and S; theoretical mention and mathematical simulation.

Type 3: Papers of this type have minor theoretical discussion about project dynamics relative to types 1 and 2, and they focus mainly on the provided model. So, papers of type 3 would only have S; which is the mathematical system dynamics models. The work of Love et al. (2000) is an example of this type.

In this research, a reference matrix is a table having the 25 dynamic parameters as rows and the different sources as headers. Each column in the references matrix represents a paper from the literature, and each row represents a dynamic parameter. The function of the references matrix is to display which of the dynamic parameters are mentioned/used in which paper (mentioned or used depends on the type of paper). If a parameter is mentioned/used in a paper, then the corresponding cell would have a value of 1; otherwise it would have a value of 0. Figure 4.2 demonstrates in a hypothetical example the concept of the reference matrices. In that hypothetical example, in reference matric M, only parameters P_i and P_{i+1} are discussed in source j+1; that is why their corresponding cells have the value of 1 while cells of other parameters a value of 0 under source j+1, and so on.

Reference Matrix M

Dynamic Parameters	Source j	Source j+1	Source j+2	…	Source J
P_i	1	1	0	0	1
P_{i+1}	0	1	0	1	1
…	1	0	1	1	1
P_n	0	0	1	1	1

Reference Matrix S

Dynamic Parameters	Source k	Source k+1	Source k+2	…	Source K
P_i	1	0	0	0	1
P_{i+1}	0	0	0	1	0
…	0	1	0	1	0
P_n	0	1	1	1	1

Reference Matrix S'

Dynamic Parameters	Source n	Source n+1	…	Source N
P_i	1	0	0	0
P_{i+1}	0	0	0	1
…	0	1	0	1
P_n	0	1	1	1

Figure 4.2. A Hypothetical Example Demonstrating the Concept of Reference Matrices.

Reference matrix M is for the sources that contained theoretical discussions of the dynamic parameters; which are papers of type 1 and type 2. The function of this reference matrix is to show what the literature says about these dynamic parameters in general and highlight which of these parameters are more important than the others. On the other hand, *reference matrix S* is for the sources that contained fully developed SD models that simulate the parameters, which are papers of type 2 and type 3. The function of this matrix is to provide insights on the current status of the developed SD models in terms of which parameters have been simulated or considered in each system dynamics model. Another view could be that matrix M represents what is the opinion of the academic and professional community of the parameters, and matrix S shows which of the parameters have been actually simulated using system dynamics. By comparing between these two matrices, the gap between "what should be studied" and "what is actually has been studied till now" could be identified to be able to direct future research into "what are the missing links that should be focused on?". Finally, *reference matrix S'* is similar to reference matrix S but with removing the sources that did not provide enough data about the how the system dynamics models are developed, and hence make it impossible for researchers to replicate their models or integrate them. So, reference matrix S' shows which parameters have been modeled using SD and at the same time the sources provide enough data about the SD models so that such models could be replicated.

In the conducted meta-analysis, the formed reference matrices had the following number of references: (1) reference matrix M had 31 sources; (2) reference matrix S had 32 sources, and (3) reference matrix S' had 17 sources. To analyze the matrices and obtain meaningful quantifiable conclusions, two types of analysis were conducted; a simplified one and an advanced one using social network analysis (SNA).

4.3.2.1 <u>*Simplified Analysis*</u>

In this type of analysis, a score is calculated for each dynamic parameter in each reference matrix by summing all corresponding cells in the row as shown in Equation 4.6. So, a score of parameter P1 of 15 in matrix M means that this parameter is discussed in 15 of the investigated sources and recommended by these sources to be part of the dynamic analysis of project management. For the same parameter, if it has a score of 10 in matrix S, this means that it is simulated in 10 of the available system dynamics models in the studied literature. Since the total number of sources in each of the reference matrices is different, a normalized score is developed to ensure proper comparison among the matrices. The normalized score of a parameter i in a reference matrix is the score of that parameter divided by the maximum score in the analyzed matrix as shown in Equation 4.7. As such, the normalized score of any parameter in any reference matrix ranges from 0 to 1.

$$Score_i = \sum_{x=first\ source\ in\ the\ matrix}^{last\ source\ in\ the\ matrix} W_{i,x} \qquad \text{Eq. (4.6)}$$

$$Normalized\ Score_i = \frac{Score_i}{Maximum\ Score_i\ in\ the\ Matrix} \qquad \text{Eq. (4.7)}$$

Where, $Score_i$: the score of parameter number i, and $W_{i,x}$: the value of the cell associated with parameter number i in source number x in the relevant matrix.

The simplified analysis is applied to all three reference matrixes and the results are shown in Figure 4.3. In the figure, the normalized score M can be seen as the "frequency of presence of the parameter in theoretical discussions" and that of S as the "frequency of actual practical presence of the parameter in the current SD models". It should be noted that the scores do not represent the importance of the parameters; but rather their frequency of use. It could be hypothesized that the frequency of mentioning a parameter in previous theoretical discussions provides an indication of its importance. This level of abstraction is acceptable in this research as the goal is to pinpoint the parameters that are ill-studied; meaning that they not frequently included in current SD models. As such, the focus here is on the frequency, not the relative importance.

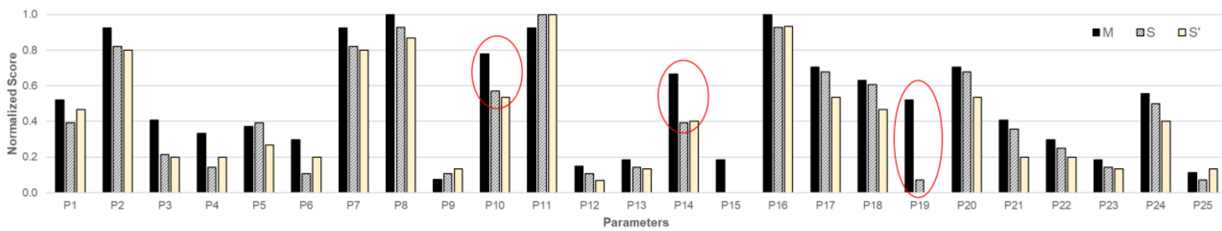


Figure 4.3. Results of the Simplified Analysis.

It can be seen in Figure 4.3 that the parameters with the highest scores in the three reference matrices are P16, P11, P8, P2, and P7; which are rework in execution, resource allocation, productivity of workforce, schedule pressure, and ripple effects of schedule pressure, respectively. This means that these parameters are most common ones that are 1) mentioned in the literature from a theoretical standpoint, and 2) included in system dynamics models studying project management aspects. The figure also enables identification of the gaps between the theoretical recommendations M and the actual developed simulation models S till date. The largest gaps are in parameters P19, P14, and P10; which are out-of-sequence work, overtime and added shifts, and resource development, respectively. This means that these three parameters are not well-studied with reference to their "should be studied" component. In other words, there is a shortage of dynamic models that study and simulate these parameters. Another interesting finding is the P15 – technology has never been included in SD models despite being of a considerable importance given its normalized M score. More discussion is present in the "Discussion of the Findings" sub-section.

4.3.2.2 <u>Social Network Analysis (SNA)</u>

The simplified analysis did not consider the inter-connectivity among the different parameters. That is why another method is needed to identify how the parameters are connected to each other;

and hence, get a better image of their importance and gaps. For this, SNA is used. SNA is a mathematical methodology abstracted from graph theory to investigate the behavior of networks while considering the interconnectivity of their members (Otte and Rousseau 2002). Original studies of SNA have been focused on the social and political relationships between individuals; where a social network denoted patterns of ties such as bounded groups (e.g., tribes, families) and social categories (e.g., gender, ethnicity) (Moreno 1960, Chinowski et al. 2008). However, given its ability to analyze networks in a holistic manner rather than in an isolated manner, SNA has been used later in several aspects such as public health (Pow et al. 2012), information exchange (Pryke 2004), business organizations (Lusher et al. 2012), transportation planning (El-adaway et al. 2016), and construction safety (Eteifa and El-adaway 2017). A network is built-up from nodes (vertices) and edges connecting between these vertices. In other words, nodes are the individuals or units that make up the social network and edges are the connecting elements that form a relationship between them (El-adaway et al. 2016).

The concept of centrality was first applied to communication by Bavelas (1948) and since then it has been probably the most used concept in SNA (Ahuja et al. 2003). Centrality describes the power and influence of a node based on how well connected it is (Park et al. 2011). Degree centrality is a measure of how many connections one node has to other nodes. Nodes which have more ties may have multiple alternative ways and resources to reach goals—and thus are more central, or important to the network.

In the scope of this research, for matrix M, degree centrality is a measure of the importance of the dynamic parameters abstracted from the frequency of use in theoretical discussions. For matrix S, degree centrality is a measure of the frequency of inclusion of the dynamic parameters among others in the available system dynamics models. The methodology for using SNA in this research has been used before in Wambeke et al. (2012) and Eteifa et al. (2017) but for different applications. Wambeke et al. (2012) used degree centrality to identify the key trades that are working together in drywall contracting and how they are related to one another. Eteifa et al. (2017) used SNA to identify key root causes of construction fatalities and how they interact with one another.

To obtain the degree centrality for the nodes of any network, an adjacency matrix has to be formed for such network first by multiplying the desired reference matrix of by its transpose and replacing the diagonals of the resulting matrix by zeros as demonstrated in Figure 4.4.

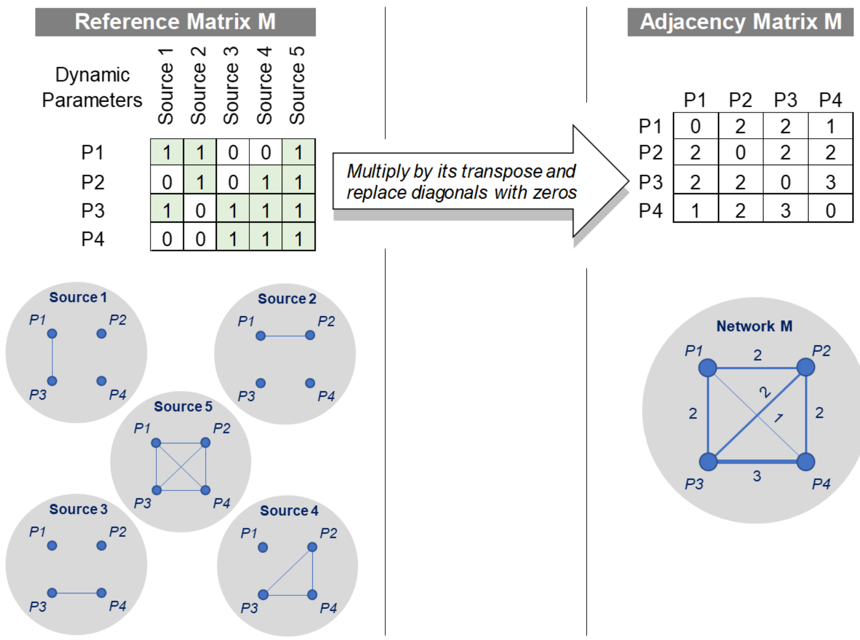


Figure 4.4. Demonstrating the Adjacency Matrix (Hypothetical Case).

The numbers in the reference matrices represent the relationship between the dynamic parameters and the sources. In the left side of Figure 4.4, source 1 mentions P1 and P3 so these parameters are connected together with an edge if we are to plot a diagram for that source. Instead of plotting a diagram for each source in each reference matrix, one network for each reference matrix should be plotted through the use of adjacency matrices. The adjacency matrix shows the inter-relationships among the dynamic parameters. So, in the right-hand side of Figure 4.4, the adjacency matrix shows that P1 is mentioned concurrently with P2 two times and P3 with P4 concurrently three times. The numbers in the adjacency matrix are also referred to as “link strength”; which show how strongly are the parameters linked to one another. It should be noted that the numbers in Figure 4.4 are of a hypothetical example just to demonstrate the concept.

To this end, three adjacency matrices have been formed, one for M, one for S, and one for S’. From such matrices, the degree centrality of each parameter is calculated as shown in Equation

4.8; where D_i is the degree centrality of parameter i and $y_{i,j}$ is the value in row i and column j of the relevant adjacency matrix. Graphically, degree centrality of a node could be calculated by adding the number of ties that are connected to it; where a link with a weight of *n* is considered to have n ties. To be able to compare between the different networks, a normalized degree centrality is used. The normalized degree centrality of a parameter i in a network is the degree centrality of that parameter divided by the maximum degree centrality in the analyzed network as shown in Equation 4.9. As such, the normalized degree centrality of any parameter in any network ranges from 0 to 1.

$$D_i = \sum_{j:j \neq i} y_{i,j} \qquad \text{Eq. (4.8)}$$

$$Normalized\ D_i = \frac{D_i}{Maximum\ D_i\ in\ the\ Network} \qquad \text{Eq. (4.9)}$$

The normalized degree centralities of the parameters are calculated and visually represented in the left part of Figure 4.5; where the node size is directly proportional to the normalized degree centrality of the associated dynamic parameter. The figure shows 3 networks, namely M, S, and S'. The networks show that all parameters are tied with one another. The strength of these ties is represented in the right part of the figure; where both the rows and the columns represent the dynamic parameters. The color of each cell represents the strength of the link between the two parameters associated with the row and column of the matrix.

By looking at Figure 4.5, it seems that there are similarities when it comes to the normalized degree centralities of most parameters between networks M, S, and S'. For example, P7 and P8 have high normalized degree centralities in M, S, and S'; which indicates that these two parameters are not just theoretically mentioned (for M) or mathematically simulated (for S and S') in high frequency, but also mentioned and simulated alongside other parameters indicating their importance within the network. However, parameters such as P19 have significantly larger normalized degree centrality in network M than in network S and S'. This illustrates that there is a gap between the recommendation of the literature and the actual developed models when it comes to these parameters.

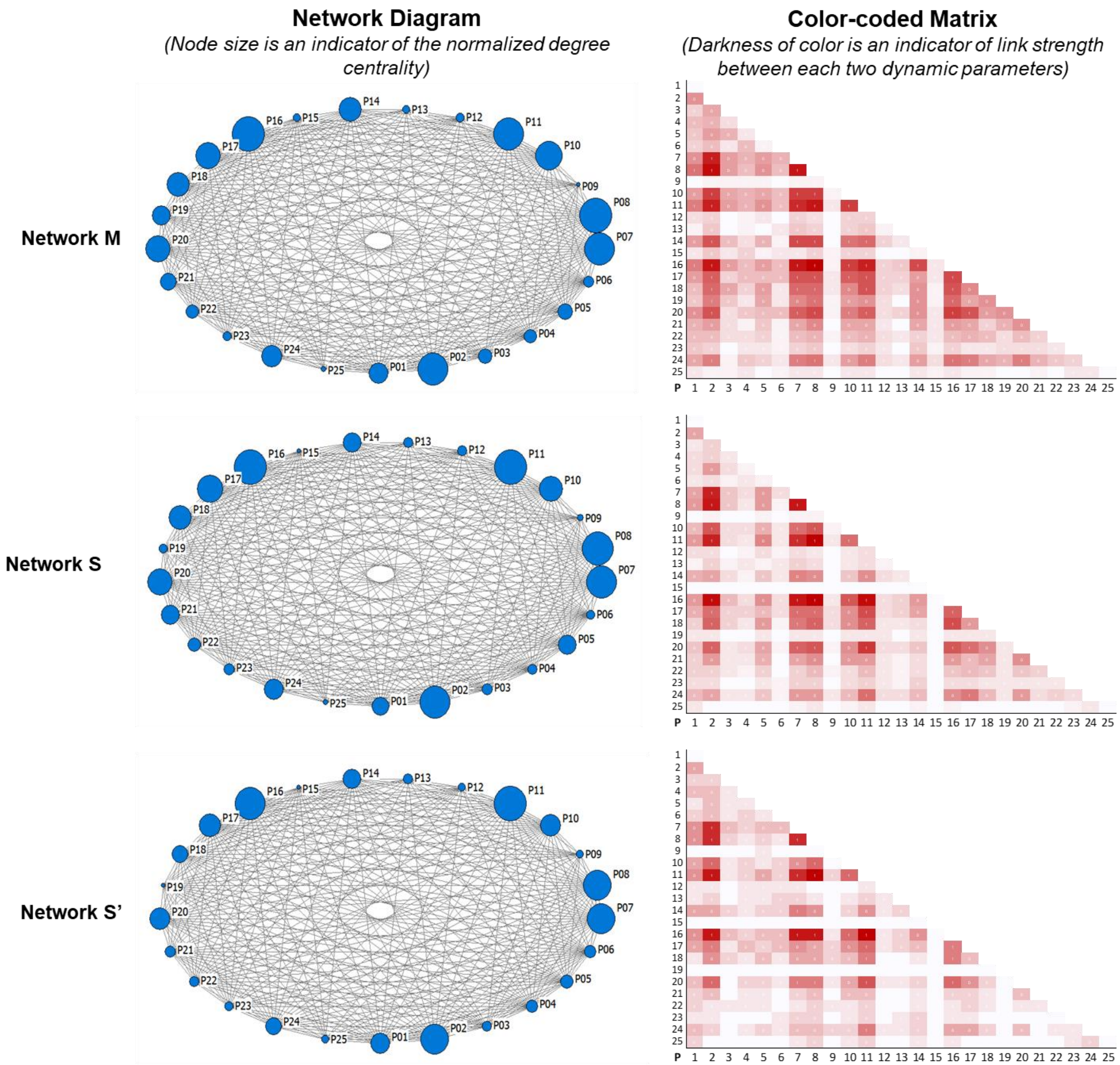


Figure 4.5. Results of the Social Network Analysis.

4.3.3 Knowledge Gaps

Table 4.4 shows the detailed normalized scores and normalized degree centralities of the dynamic parameters in the different matrices/networks. Figure 4.6 shows that difference between the normalized scores of the parameters in matrix/network M and those in matrix/network S using both the simplified analysis and the SNA approaches.

The following bullet points provide a concise discussion on the findings and the identified knowledge gaps:

- Just by simple visual inspection of the right part of Figure 4.5, network M is denser than networks S and S' in the sense that it has more strong links than those in networks S and S'. This indicates the following: despite that the literature highlight the importance of investigating the dynamic parameters inter-connectively instead of doing so separately, the actual available models study and simulate these parameters in an "isolated islands" manner; where each simulation model focuses of specific parameters and leaves out the rest.

- The most significant parameters that should be included in construction project management SD models are those which have the highest normalized score in matrix M and normal degree centrality in network M. Those parameters are P2 (schedule pressure), P7 (ripple effects of schedule pressure), P8 (productivity of workforce), P11 (resource allocation), and P16 (rework in execution). Those parameters have normalized scores and normalized degree centralities higher than 0.8 in all M, S, and S' matrixes/networks. This indicates that there is a consensus between the theoretical discussions and the actual simulation availability when it comes to these parameters.

- Results from the simplified analysis and the SNA both indicate that ***the highest gap between M and S is present in parameter P19 (out-of-sequence work)*** as shown in Figure 4.6. The gap in this parameter is around double that of the following parameter; which is P14 (overtime and added shifts). This indicates that although out-of-sequence work is a key parameter that impacts project progress, its presence in simulation models is way

Table 4.4. Results of the Literature Meta-Analysis.

Co-de	Dynamic Parameters	Using Simplified Analysis					Using Social Network Analysis (SNA)				
		Normalized Score			Difference in Normalized Scores		Normalized Degree Centrality			Difference in Normalized Degree Centralities	
		Matrix M	Matrix S	Matrix S'	M-S	M-S'	Network M	Network S	Network S'	M-S	M-S'
P1.	Realistic Scheduling	0.519	0.393	0.467	0.126	0.052	0.564	0.471	0.536	0.093	0.029
P2.	Schedule Pressure	0.926	0.821	0.800	0.104	0.126	0.946	0.921	0.857	0.026	0.089
P3.	Complexity	0.407	0.214	0.200	0.193	0.207	0.375	0.238	0.205	0.137	0.170
P4.	Coordination and Communication	0.333	0.143	0.200	0.190	0.133	0.346	0.189	0.277	0.157	0.070
P5.	Efficiency of the Approval Process	0.370	0.393	0.267	-0.022	0.104	0.446	0.511	0.321	-0.065	0.125
P6.	Trust and Motivation	0.296	0.107	0.200	0.189	0.096	0.275	0.141	0.286	0.134	-0.011
P7.	Ripple Effects of Schedule Pressure	0.926	0.821	0.800	0.104	0.126	0.936	0.916	0.848	0.019	0.088
P8.	Productivity of Workforce	1.000	0.929	0.867	0.071	0.133	1.000	0.969	0.830	0.031	0.170
P9.	Constructability Reviews	0.074	0.107	0.133	-0.033	-0.059	0.071	0.084	0.107	-0.012	-0.036
P10.	Resource Development	0.778	0.571	0.533	0.206	0.244	0.818	0.687	0.589	0.131	0.229
P11.	Resource Allocation	0.926	1.000	1.000	-0.074	-0.074	0.946	0.996	1.000	-0.049	-0.054
P12.	Absenteeism and Turnover	0.148	0.107	0.067	0.041	0.081	0.207	0.207	0.116	0.000	0.091
P13.	Workplace Congestion	0.185	0.143	0.133	0.042	0.052	0.179	0.198	0.205	-0.020	-0.027
P14.	Overtime and Added Shifts	0.667	0.393	0.400	0.274	0.267	0.693	0.489	0.482	0.204	0.211
P15.	Technology	0.185	0.000	0.000	0.185	0.185	0.175	0.000	0.000	0.175	0.175
P16.	Rework in Execution	1.000	0.929	0.933	0.071	0.067	0.989	1.000	0.938	-0.011	0.052
P17.	Rework in Design	0.704	0.679	0.533	0.025	0.170	0.757	0.758	0.634	-0.001	0.123
P18.	Reliability of Quality Assurance Staff	0.630	0.607	0.467	0.022	0.163	0.661	0.670	0.429	-0.009	0.232
P19.	Out-of-Sequence Work	0.519	0.071	0.000	0.447	0.519	0.550	0.150	0.000	0.400	0.550
P20.	Controlled Change	0.704	0.679	0.533	0.025	0.170	0.746	0.740	0.580	0.006	0.166
P21.	Uncontrolled Change	0.407	0.357	0.200	0.050	0.207	0.450	0.485	0.250	-0.035	0.200
P22.	Fabrication Quality	0.296	0.250	0.200	0.046	0.096	0.357	0.326	0.188	0.031	0.170
P23.	Communication with Fabricators	0.185	0.143	0.133	0.042	0.052	0.225	0.225	0.152	0.000	0.073
P24.	Financial Estimating	0.556	0.500	0.400	0.056	0.156	0.596	0.555	0.411	0.041	0.186
P25.	Budget Contingency	0.111	0.071	0.133	0.040	-0.022	0.096	0.057	0.116	0.039	-0.020

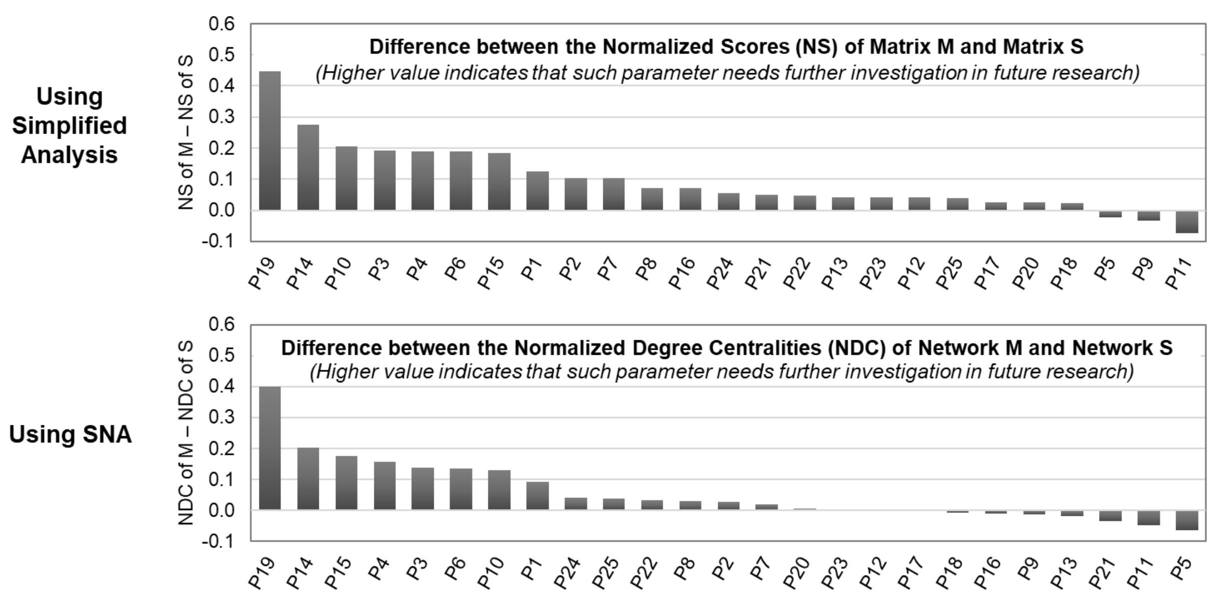


Figure 4.6. Difference between Normalized Scores/Degree Centralities of the Dynamic Parameters.

below the expected or deserved level. In fact, out-of-sequence work is rarely simulated in SD models as it has one of the lowest normalized scores and degree centralities. More interestingly, even in the rare occasions of having out-of-sequence work simulated, the methodology of such inclusion is not provided; hence out-of-sequence work has a score and degree centrality of 0 in the S' matrix/network. This means that researchers do not have access to having out-of-sequence work as part of a SD model for construction project management. ***This highlights the fact that there is a knowledge gap in dynamic modeling when it comes to out-of-sequence work***.

- Almost all parameters other than out-of-sequence work have been simulated or at least their dynamics have been discussed in stand-alone endeavors. For example, Alvanchi et al. (2012) specifically tackled the dynamics of working hours primarily in terms of the effect of working hours on fatigue and productivity (P14, P7, and P8). Another example, Li and Taylor (2014) primarily focused on the dynamic impact of design rework (P17) on project performance. However, ***no theoretical or mathematical SD models have been discussed or developed tackling the dynamics of out-of-sequence work as a primary topic***. As such, this bullet point and the previous bullet point highlight the need for further research focusing on the dynamics of out-of-sequence work.

- One of the interesting findings is that ***the dynamics of technology (P15) have been theoretically discussed but have never been included in simulation models***. This also highlights the need for inclusion of such parameter in future SD models of construction project management.

- When it comes to resource allocation (P11), in very few papers in the literature, the developed models actually had the ability to determine the amount of needed resources. In the majority of the models, the user inputs the total available human resources and the model just allocates them among the different design, execution, quality assurance, and rework tasks. ***There is a need for advanced models to have the ability to assess the project progress and determine the forecasted needed resources***. Models need to have the ability to determine "how many staff members does the project need?" and "how are we going to allocate the available staff on the different design, execution, quality assurance, and rework tasks?" at any point in time. Most of the current models can answer only the first question.

- One of the most significant findings is that no system dynamics model in the literature (either in the S or S' matrices) included all of the 25 dynamic parameters simultaneously. For matrix S, the maximum number of simultaneous parameters included in a model was 18. If we exclude those models that are not replicable (thus only considering S'), the maximum number of simultaneous parameters would be 14 out of 25. As such, ***none of the models had the ability to simulate the construction project management process in a true holistic manner***. This highlights the need of advanced system dynamics models that address the 25 dynamic parameters simultaneously for a true holistic management and control of construction projects.

4.4 Objective

The objective of this chapter is to develop an advanced systematic model for analyzing the dynamics of out-of-sequence work. This is covered in Sections 4.5 to 4.10. This covers the most pressing knowledge gaps; which are (1) the lack of models that analyze the dynamics of OOS, and (2) the need for advanced models to have the ability to assess the project progress and determine the forecasted needed resources. Section 4.11 provides guidelines and conceptual framework that guide future researchers on how to addresses the remaining gaps.

4.5 Background Information about Out-of-Sequence (OOS) Work from a Dynamic Perspective

OOS work is defined by Ibbs et al (2017) as "*a condition in which the originally planned, and probably most efficient and logical, work sequence is interrupted and changed*." This change could be in terms of changes in the specifications, plans, design, equipment, materials, used technology, temporary facilities, time of performance, personnel, construction method, and external conditions (US Government 1984). According to Sterman (1992), changes are the norm rather than the exception in construction projects. Rearranging the work to accommodate change without fully contemplating the project's interrelated feedbacks leads to productivity loss, and added costs.

For example, if the material for an activity arrives late, the crews whom are assigned to this activity will be assigned to another activity by the contractor to maintain work continuity. If this rearrangement is made while considering the associated complexities, the impacts would be minimal. However, if complexities are not well-considered and planned for, the impacts could be significant. An example of complexities is the additional time taken in the process of moving back and forth between the skipped activity and the newly assigned activity due to transporting the staff and reorienting the workers to the new sequence that could be confusing to them. The impact of OSS work is even rippled when the skipped-to activity is not completed and the crews are re-assigned to the original activity or to a new activity. Also, the pace of the workers tends to slow down when the sequence changes (Ibbs et al 2017).

Numerous studies have been made to investigate causes of labor productivity loss, of which OOS work is a major cause. However, very few focused on OOS work as a stand-alone subject in itself. Moreover, investigating and modeling the dynamics of OOS work has never been attempted before. As such, when OOS work takes place, project parties lack the proper understanding to analyze its rippled impacts and fail to formulate proper policies to mitigate or prevent these impacts. In addition, they fail to resolve claims related to the corresponding disruption before turning into disputes because the traditional schedule analysis techniques fail to grasp the indirect and dynamic impacts of such disruptions (Rodrigues and Williams 1998; Ibbs et al 2017).

4.6 Model Development

This paper uses a multi-step interdependent research methodology. First, a dynamic hypothesis is formed; where it clarifies the scope and explains the dynamics of the feedback structure of the problem in hand. Second, a SD simulation model is developed by integrating quantitative mathematical formulations to the dynamic hypothesis. The simulation model is formed of five different inter-connected modules; namely workflow, progress rate, disruption, staffing, and staffing distribution modules. Third, a multi-stage calibration algorithm is developed to ensure that the model is able to replicate real projects. Fourth, the model is verified using standard verification tests. Fifth, the model is used in an actual case study by calibrating parameters to replicate the project's planned and actual conditions. After calibration, different what-if scenarios were modeled and analyzed to demonstrate some of the model's diagnostics and forecasting capacities that could help parties in analyzing the dynamics of OOS. Figure 4.7 shows a summary of the research methodology. The following sections explain the different methodological steps in more details.

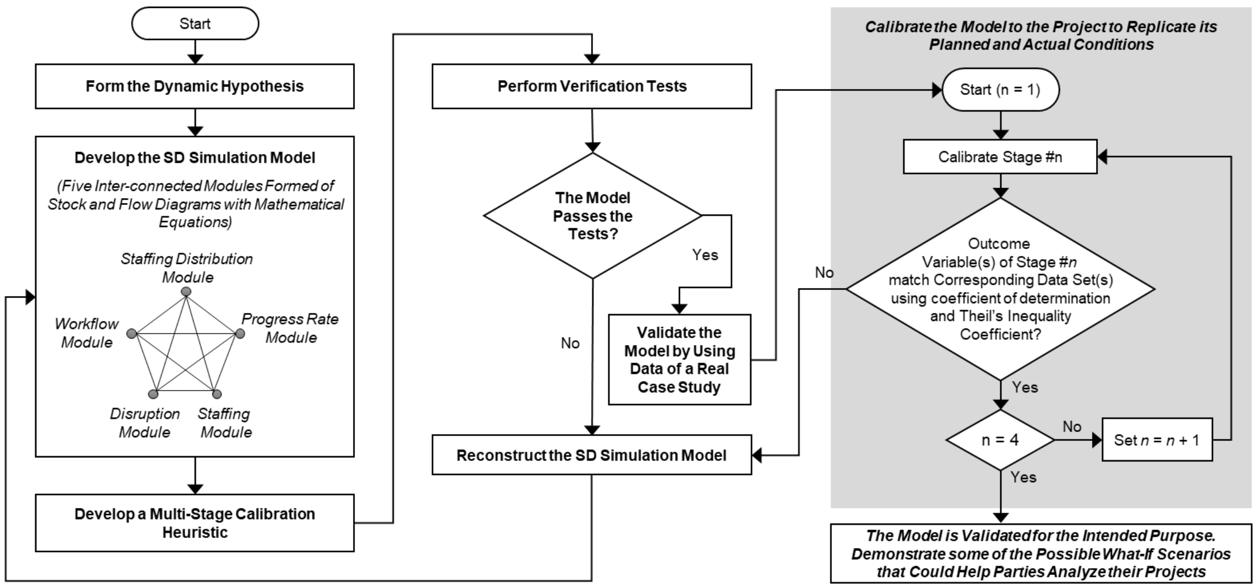


Figure 4.7. Methodology for Developing the SD Model.

4.6.1 Forming the Dynamic Hypothesis and Developing the Simulation Model

The first step is forming the dynamic hypothesis. A dynamic hypothesis is one that explains the dynamics as endogenous consequences of the feedback structure. Such formation is through causal structures based on initial hypothesis, key variables, reference modes, and other available data. In a more relevant language, the dynamic hypothesis is a set of cause-effect relationships for the main elements responsible for OOS work, schedule overruns, time overruns, rework, and other attributes related to the project based on the problem in hand. The two main diagrams for representing the dynamic hypothesis are causal loop diagrams and stock and flow diagrams.

In causal loop diagrams, variables are connected to each other by arrows; where the arrow represents causal relationship. As shown in Figure 4.8, the broad idea that is driving the rest of the formulations and derivation is that staffing, progress rate, OOS work, and progress are interrelated. The positive sign in the figure indicates a directly proportional relationship and a negative sign indicates an inversely proportional relationship. The earned value represents the progress of the project. It is directly impacted by the progress rate; which is closely related to the overall productivity. The earned value is also impacted by disruption in terms of quality decline. With less quality, rework increases, thus slowing the rate at which the project is progressed and resulting in reduction of the earned value sometimes. The progress rate is impacted by staffing and the OOS activities. Logically, more staffing means more overall productivity, leading to higher progress rate. The amount of OOS work has an impact on progress rate in terms of lowering the workers' productivity. This relationship has been mentioned in the literature but only qualitatively and secondarily. What closes the cycle is the link between earned value and staffing. At any point in time, if the actual earned value is less than the planned earned value, then the staffing needs to increase, and vice versa.

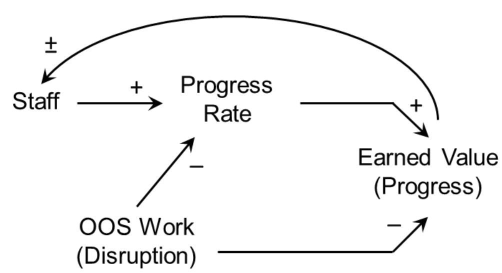


Figure 4.8. The Broad Dynamic Hypothesis.

Figure 4.8 only shows the broad causal loop of the dynamic hypothesis. However, behind each of the terms in the figure there are tens of variables that are co-related, interrelated, and integrated in a stock and flow diagrams. Co-related means that the variables under the same term are linked, and interrelated means that the variables of the different terms are linked.

The stock and flow diagrams and the causal feedback loops diagrams represent the dynamic hypothesis; and feeding these diagrams with mathematical equations and quantitative data transforms them from being the dynamic hypothesis into being the simulation model. As such, and to save writing space, it is efficient to present and discuss only the simulation model since it already includes the dynamic hypothesis within its premises.

The following sub-sections provide detailed discussions on the different inter-connecting modules of the developed SD model; namely: (1) workflow module; (2) progress rate module; (3) staffing distribution module; (4) disruption module, and (5) staffing module. The following sub-sections will discuss each module separately then present the interaction among these modules.

4.6.2 Workflow Module

This is the main module in the model. It borrows its conceptual foundation from the model proposed by Taylor and Ford (2008) and Li et al (2014), with few changes to suit the purpose of the paper in hand. In the developed model, as in the rest of the similar SD models, construction activities are not modeled as tasks, but rather as flow of work units. Work units in the context of this paper - and actually several other SD studies - represent the progress of work in terms of dollar value. In production systems and lean construction, there could be multiple work units representing the different trades of work. For example, work units could represent the number of rooms painted by the painting crew. However, in the scope of this study, and most of the relevant SD studies, the model looks at a macroscopic level of aggregation; where the differentiation between the production rate of the different trades is made in the progress rate module (the following sub-section in the paper). Instead of having multiple types of trade-specific work units, the model has a fixed work unit representing the dollar value, and multiple phase-specific progress rates. These progress rates represent the volume of dollars' worth of work the crews are able to finish in one unit of time. In the model's case, the unit of time is weeks.

It is easier to explain how the work units are modeled in stocks and flows through visualizing a volume of water that needs to get transferred from one tank to another. The first tank represents the work that needs to be performed and the receiving tank represents the work that is finished and approved. The water flows one droplet at a time. Each droplet is a "work unit". In Figure 4.9, boxed variables represent the units of work - tanks in this case - that must be completed to finish the project. When each work unit is completed, it moves from its backlog to the next backlog through the valve symbol; which controls the speed of work flow between the backlogs in term of how many work units can pass through at a time.

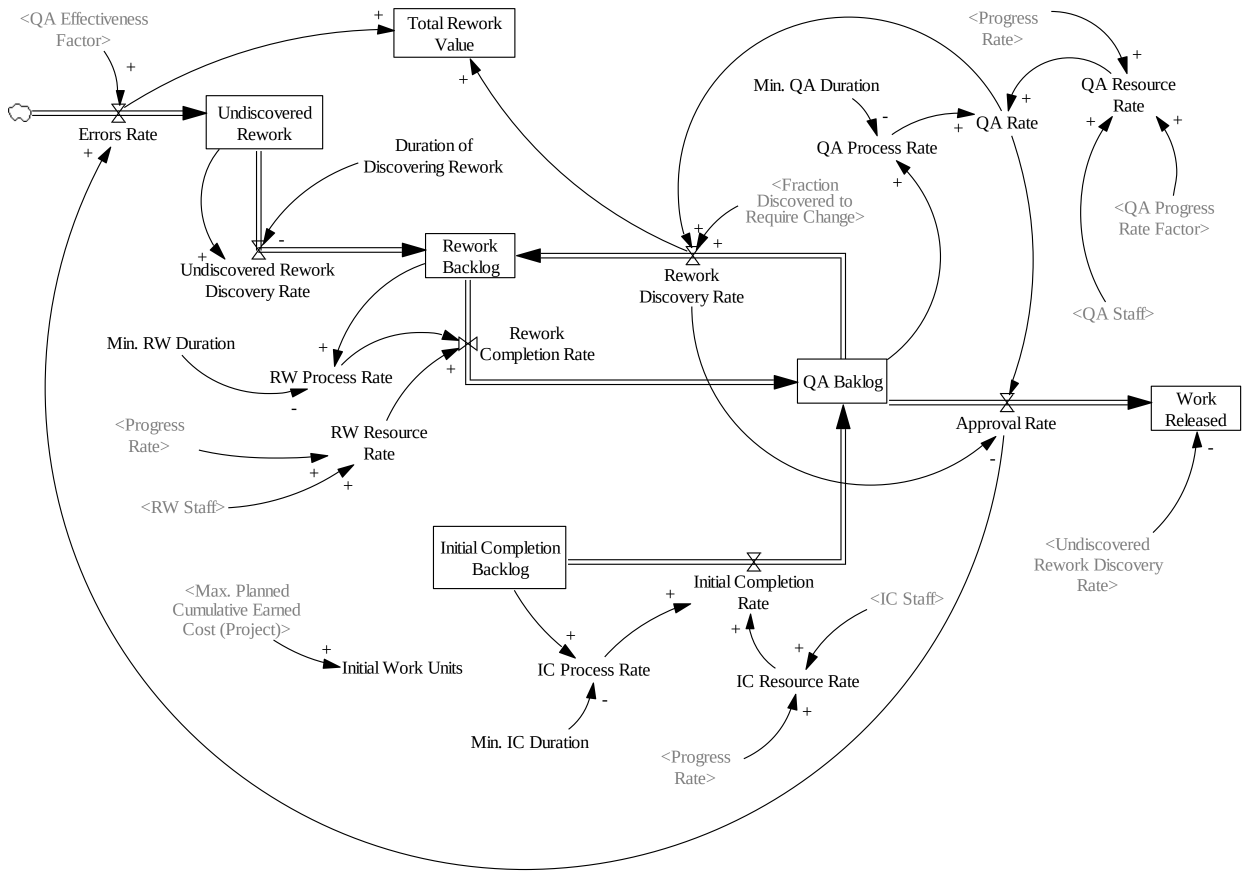


Figure 4.9. The Model's Workflow Module.

To further explain Figure 4.9, completed work by the construction workers moves from the "initial completion backlog" to the "quality assurance (QA) backlog" and waits there to be checked by the QA engineers. From there, the work that is approved is moves to the "work released backlog" and that which is not approved moves to the "rework backlog" where workers will be asked to perform the unapproved work again. In the developed model, the work units are represented with the dollar value of the project. Accordingly, the "work released backlog" represents the earned value of the project at any given time; thus, characterizing the project's progress. The percentage of approved work, which is an indication of the quality of work, is determined by the variable named "fraction discovered to require change". The reworked work units move to the "QA backlog" again for further assessment. The model takes into consideration that some of the work units that are already approved by the QA staff might be faulty or require change through errors, omissions, or regulation changes. This is accounted for through the "undiscovered rework backlog" which contains such lately discovered work units and transfers them to the "rework backlog". The variable that controls such mistakes by the QA team is the "QA effectiveness factor". This factor represents the percentage of faults by the QA team (i.e. approving defective work instead of rejecting it). The "fraction discovered to require change" and "QA effectiveness factor" variables are impacted by several factors such as disruption and OOS activities. Accordingly, they are not just static numbers, but rather dynamic values that change over the course of the project.

The flows among the different backlogs are constrained by either development process (i.e. process rate) or available resources (i.e. resource rate). So, for example, the "initial completion rate" is the minimum of the "Initial Completion (IC) process rate" and the "IC resource rate"; where the "IC process rate" is the minimum duration for a work unit to be undertaken (project-specific) and the "IC resource rate" depends on the number of available IC staff (i.e. construction workers) and their productivity at the time of calculation. Some of the grey colored variables in Figure 4.9 are inputs from other modules of the model. Also, some of the black colored variables act as inputs to other modules. Important equations related to this module are:

$$Total\ Rework\ Value_t = \int_0^t Errors\ Rate + Rework\ Discovery\ Rate \qquad \text{Eq. (4.10)}$$

$$Resource\ Rate_t = Staff_t \times Progress\ Rate_t \qquad \text{Eq. (4.11)}$$

$$Rework\ Discovery\ Rate_t = MAX\ (Fraction\ Discovered\ to\ Require\ Change_t \times QA\ Rate_t, 0\ ) \qquad \text{Eq. (4.12)}$$

$$Errors\ Rate_t = Approval\ Rate_t \times (1 - QA\ Effectiveness\ Factor_t) \qquad \text{Eq. (4.13)}$$

4.6.3 Progress Rate Module

This module is responsible for determining the progress rate of the project at any given time. In the developed model, the progress rate is the number of work units that could be performed by a unit of staff in a time step. Each time step in the developed model represents a week. The selection of the time step could vary from one project to another. For projects with short durations (less than a year), it is recommended to use days as the time step unit.

This module is based on the fact that each project goes through different phases; where each phase requires its own type of construction staff and has its progress rate (i.e. speed of earning value). In other words, the progress rate in the whole project is not homogenous; meaning that the amount of work finished by a man-hour in the excavation phase is not similar to the amount of work finished by a man-hour in the concreting phase in terms of dollar value. In fact, the progress rate within each phase is not homogenous in reality. For example, one man-hour in week 1 of the excavation phase does not finish the same amount of work as one man-hour in week 4 of the same phase. It would be impractical to have a different variable representing each progress rate in each time step. This would be overfitting. However, it is reasonable to assume that the progress rate within each phase is homogenous; thus, having a number of variables equal to the number of project phases instead of having them equal to the number of time steps. As such, if we are at a time step *t* that is phase 1, the rate at which work units are transferred form the IC backlog to the QA backlog is the multiplication of the progress rate of stage 1 by the number of designated man-hours of the IC staff at *t*.

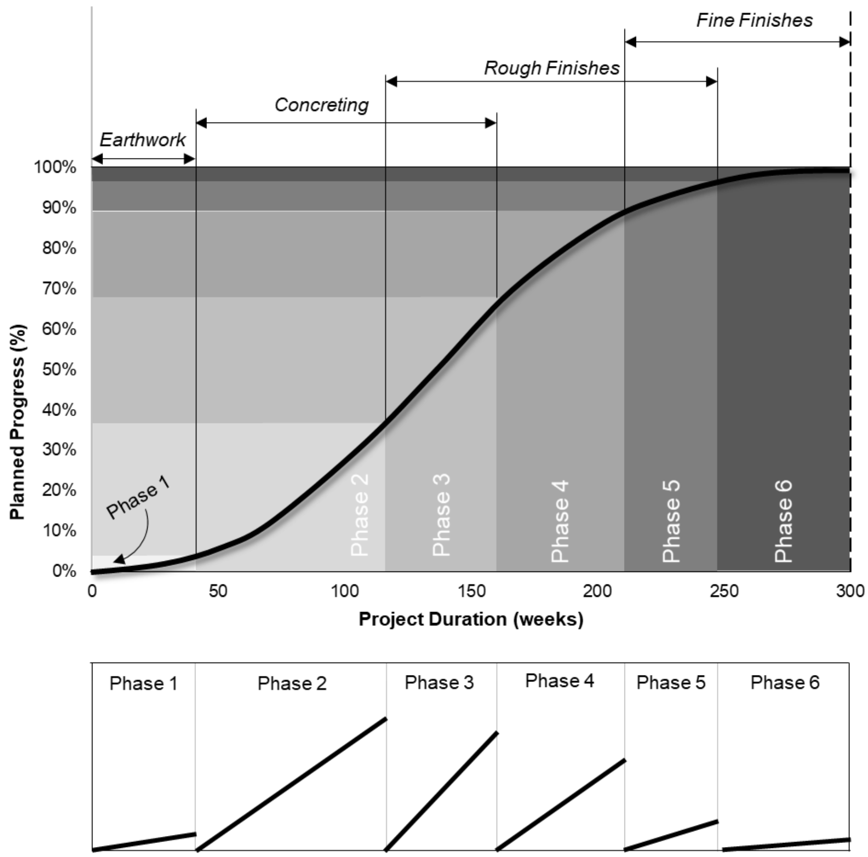
The assumption that of within-phase homogeneity is an acceptable simplification to enable modeling within reasonable capacity and efficiency. Previous works in SD modeling did not take the different phases into consideration and just assumed one progress rate for the entire project.

This restricted their ability to capture complexities and resulted in a rather narrow-windowed analysis. Since this research proposes the use of different progress rates depending on project phases, it enables grasping an additional layer of complexity and allows for enhanced and more credible analysis.

To elaborate how the different phases are incorporated in the model, consider a hypothetical project with four main types of works: earthwork, concreting, rough finishes, and fine finishes. Some of these works are overlapping as shown in Figure 4.10. The figure also shows the planned progress based on the agreed plan using the traditional scheduling techniques. Each type of work is not considered a phase on its own. For example, concreting requires concreting staff and rough finishes require rough finishes staff. But since concreting and rough finishes are overlapping, then the part of concreting works that is not overlapping is considered a separate phase because it has only concreting staff, the part overlapping with rough finishes is considered a separate phase because it has both concreting and rough finishes staff, and the part of rough finishes works that is not overlapping with anything else is considered a separate phase because it only involves rough finishes staff. By applying this concept of project phases to the rest of the works, the starting and ending percentage of planned work of each phase could be determined. For example, in the hypothetical project in Figure 4.10, when the project reaches a completion level of 38%, phase 2 ends and phase 3 starts.

The developed SD model utilizes the multiple progress rates based on project phases as shown in Figure 4.11; where the variables named "Phase # PR" represent coefficients for the differential progress rates at the different phases. At any time t, the coefficients corresponding to the relevant phase is multiplied by the average progress rate - which is constant variable – to obtain the progress rate at time t. There are several factors that impact the progress rate coefficients such as interruptions and OOS activities. Obtaining these coefficients is discussed under the sub-section covering the disruption module.

The significant equations in this module are as follows:



The lines represent the average progress rate of each phase. For modeling purposes, it is assumed that each phase is homogeneous; thus having a unified progress rate (per man hour). Within each module, the number of allocated staff at any point in time is multiplied by the average progress rate to obtain the actual progress rate of that phase. Previous models assume the entire project is homogenous. Thus, the presented model is closer to reality.

Figure 4.10. Elaborating the Concept of Phases in a Hypothetical Project.

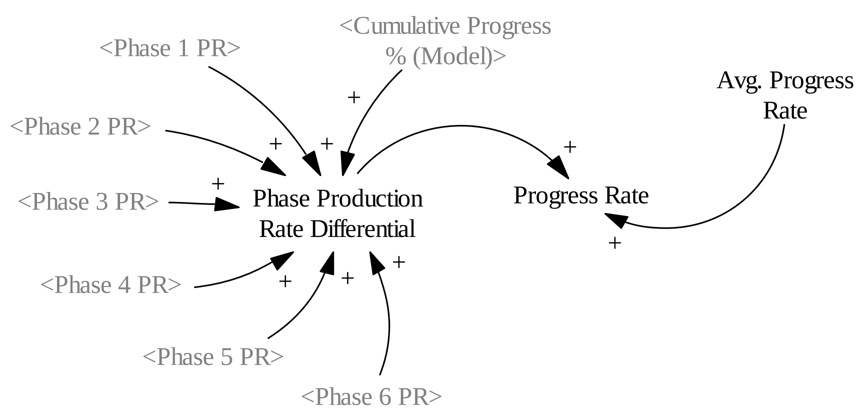


Figure 4.11. The Model's Progress Rate Module (PR: Progress Rate Coefficient).

$$Progress\ Rate_t = Avg.Progress\ Rate_t \times Phase\ Production\ Rate\ Differential_t \quad \text{Eq. (4.14)}$$

$$Phase\ Production\ Rate\ Differential_t = \begin{cases} Phase\ 1\ PR, & P_t \leq P_{1,2} \\ Phase\ 2\ PR, & P_{1,2} < P_t \leq P_{2,3} \\ & \dots \\ Phase\ N\ PR, & P_{N-1,N} < P_t \end{cases} \quad \text{Eq. (4.15)}$$

Where, P_t is the cumulative actual progress at time t, $P_{x,y}$ is the progress cutoff point at which phase x ends and phase y starts. This module is unique to this model and has not been developed in other relevant SD models.

4.6.4 Staffing Module

The staffing module is responsible for specifying the number of staff required to do the work units in the given time. This module is a significant addition to the construction SD modeling field because previous models just assume a given number of staff without having this number changing based on the project's performance. This module obtains the number of required staffing at each time step based on the project's progress relevant to the planned progress, the time left till the approved deadline, and the forecasted progress rate requirements to finish on time. Without this module, it would have been impossible to simulate the impact of OOS or disruption in general on staffing, and hence on progress. In other words, without this module, users could just run the model with the project's planned staffing and the project's actual staffing. However, they would not have been able to run different scenarios since the staffing for those scenarios are not given. The developed model, through the staffing module, is able to obtain staffing requirements for any scenario.

Two different staffing modules, namely method 1 and method 2, have been developed to suit the different analysis requirements. Method 1 of the staffing module is developed for project participants who wish to finish on a certain deadline without much emphasis on certain progress profile. In this method, the module determines the staffing at each time step that ensures the project will finish on the specified deadline; while taking the project disruptions into consideration. As such, it sets its own progress profile based on the given deadline. This method is conceptually similar to some models in the literature with changes to suit the tackled research. A limitation of this method is that it does not consider the cost during execution. To cover this limitation, method 2 was developed. Unlike method 1, method 2 of the staffing module emphasizes the approved project progress profile, meaning that the user has to input the desired project progress profile and the module would determine the staffing requirements that ensures this profile is met. Of course, to meet such profile in the presence of OOS, the staffing requirements and the corresponding costs are increased. Users can select any of the two methods depending on the project's needs and on the available data. The following paragraphs explain the two different methods of the staffing module.

4.6.4.1 Method 1 of the Staffing Module

Figure 4.12 shows the stock and flow diagram forming the staffing module – method 1. At any given time during the simulation, the module calculates the average progress rate in the previous N time steps by dividing the total work released in the previous N time steps by N. Basing future decisions on just one previous time step is not reasonable because each time step on its own has a varying behavior that is unstable. To have more confidence and better decisions, the model bases future staffing decisions on the average performance of the past N time steps. N has to be small enough to ensure that recent behavior is not diluted and large enough to ensure stability. N is specified by the user. N is recommended to be a number between one fiftieth to one seventieth of the project's time steps; with a minimum value of 3 and a maximum value of 10. So, if the project has 300 time steps, N is recommended to be between 4 and 6. The module bases the rest of its calculations on the assumption that the progress rate at any time corresponds to the staffing arrangement at that time. In other words, if no changes are made to the number of staffing (in terms of manhours) in the following time step, the progress rate will not change. Based on the that, the module forecasts the time remaining to finish the remaining work units if the same progress rate is sustained and multiplies that by a phase-related factor (referred to as Cor. Ph# in Figure 4.12). If the forecasted time remaining is more than the actual time remaining, then the module reduces the staffing for the following time step, and vice versa. For modeling simplicity, the module takes decisions of whether to increase or decrease the staffing each N time steps rather than each single time step. This has shown to reduce illogical staffing fluctuations.

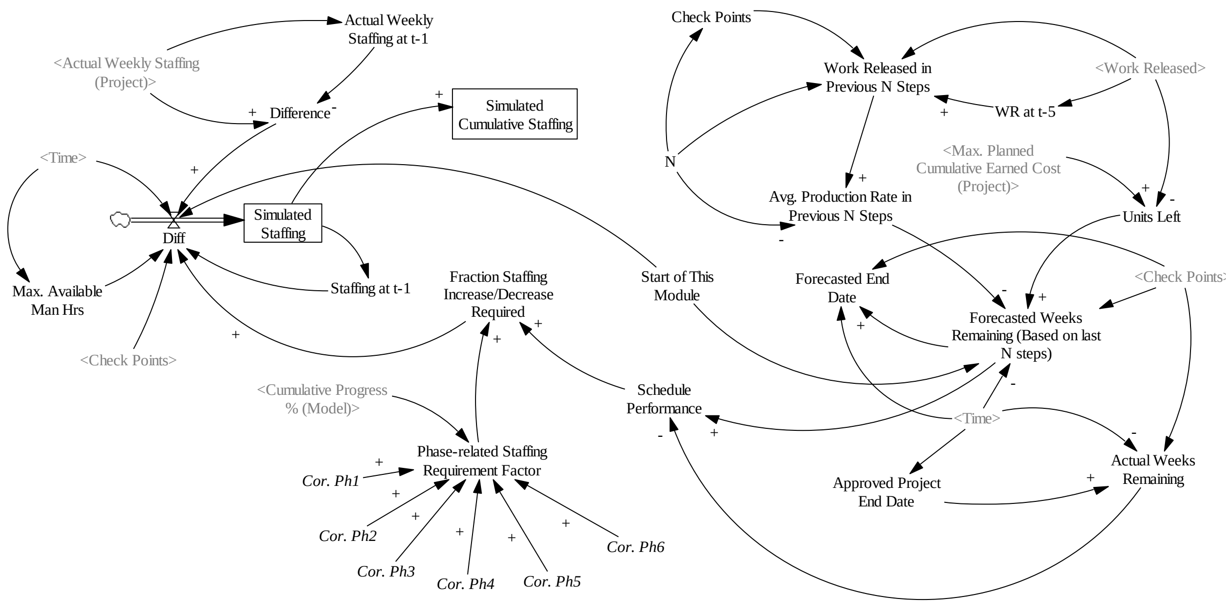


Figure 4.12. The Model's Staffing Module – Method 1 (Cor: Phase-related Correlation Factor).

To test, the project's overall average progress rate (B) was used instead of the average progress rated based on the previous N time steps (A), then the process was repeated using the project's overall average progress rate (B) instead of the average progress rated. However, it turned out that A is more accurate than B as demonstrated in Figure 4.13. In the figure, a hypothetical simulated project is at week 35. If the staffing does not change, then the progress rate would not change (hypothetically regardless of other interruption-related factors) and the progress curve would extend with the same slope as it has been in the past N time steps. In this case, N is 5, this extrapolation is more reasonable than if (B) is the slope that is extrapolated as shown in Figure 4.13.

The significant mathematical formulations in this module are as follows:

$$Forecasted\ Weeks\ Remaining_t = \frac{Work\ Packages\ Left_t}{Avg.Progress\ Rate\ in\ Previous\ N\ Steps_t} \qquad \text{Eq. (4.16)}$$

$$Schedule\ Performance_t = \frac{Forecasted\ Weeks\ Remaining_t}{Actual\ Weeks\ Remaining_t} \qquad \text{Eq. (4.17)}$$

$$\begin{aligned} &Fraction\ Staffing\ Increase/Decrease\ Required_t \\ &\qquad = Schedule\ Performance_t \qquad \text{Eq. (4.18)} \\ &\qquad \times Phase\ related\ Staffing\ Requirement\ Factor_t \end{aligned}$$

$$Phase\ related\ Staffing\ Requirement\ Factor_t = \begin{cases} Cor.Ph1, & P_t \leq P_{1,2} \\ Cor.Ph1, & P_{1,2} < P_t \leq P_{2,3} \\ & \dots \\ Cor.PhN, & P_{N-1,N} < P_t \end{cases} \qquad \text{Eq. (4.19)}$$

Where, "Cor. Ph#" variables are the phase-related adjustment factors for staffing requirements. Obtaining these factors is explained in stage 4 of the calibration process. "Schedule performance" is a measure of the simulated progress relative to the planned progress. If the value is above 1, the project is behind schedule; and if below 1, then the project is ahead of schedule. P_t is the cumulative actual progress at time t, $P_{x,y}$ is the progress cutoff point at which phase x ends and phase y starts.

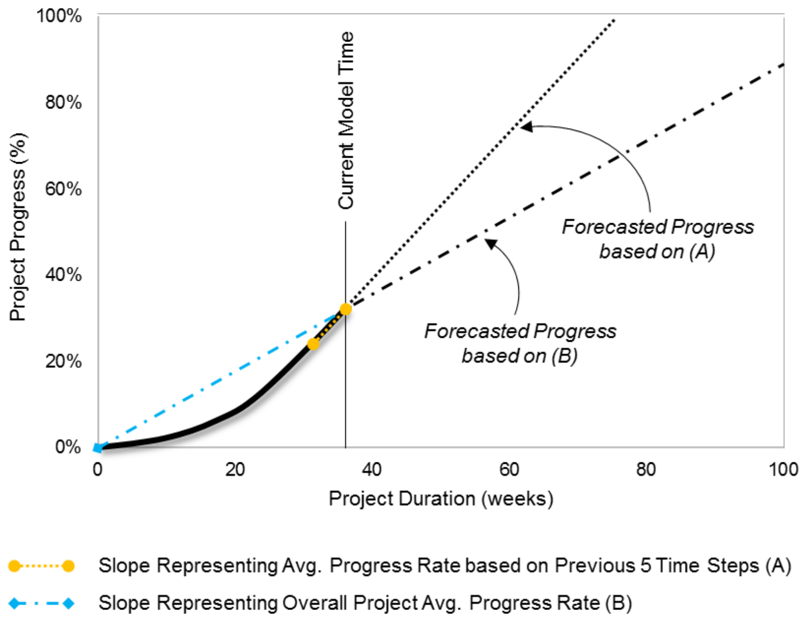


Figure 4.13. Demonstration for Calculating the Progress Rate.

4.6.4.2 Method 2 of the Staffing Module

In this method, the module attempts to abide by the given progress profile. The module calculates two parameters named the slope factor and the progress factor. These are parameters that are developed to indicate how the project progress is abiding by the approved progress. To calculate the slope factor, the module measures the slope of the project (simulated) progress (A) in the past N time steps and assumes that this slope will not change in the following N time steps if the current level of staffing is used. This slope is then compared to the slope of approved progress (B) in the following N time steps. If A is higher than B, then the staffing needs to decrease; where the objective is to make A and B match. If A is lower than B, then the staffing needs to increase. The slope factor is calculated as shown in Equations 4.20 to 4.22.

$$A_t = \frac{1}{N}\int_{t-N}^{t} Simulated\ Progress \qquad \text{Eq. (4.20)}$$

$$B_t = \frac{1}{N}\int_{t}^{t+N} Approved\ Progress \qquad \text{Eq. (4.21)}$$

$$Slope\ Factor_t = \begin{cases} \frac{B_t}{A_t}, & B_t > 0 \\ 1, & B_t = 0 \end{cases} \qquad \text{Eq. (4.22)}$$

The slope factor is not a sufficient indicator of progress by itself because A could be lower than B – indicating that the staffing needs to increase to make A match B – but at the same time the current project progress is higher than the approved project progress – which indicates that the level of staffing actually needs to decrease. This is why the parameter named “progress factor” is used with the “slope factor” to determine the required level of staffing. The progress factor is a function between the project’s forecasted progress after N time steps given the current staffing level and the approved progress after N time steps as shown in Equation 4.23.

$$Progress\ Factor_t = \frac{Approved\ Progress_{t+N}}{Simulated\ Progress_t\ (1 + A_t)} \qquad \text{Eq. (4.23)}$$

Together, the slope factor and progress factor provide correct indication of the project's progress as compared to the approved one. From these parameters, the staffing requirement factor is calculated as an average of the slope factor and the progress factor. This factor indicates the percentage that the staffing needs increased or decreased by. For example, at any time step, if the staffing requirement factor is 1.1, then the staffing needs to be increased by 10%. If it has a value of 0.9, then the staffing needs to be decreased by 10%. Figure 4.14 shows the stock and flow diagram forming the staffing module – method 2. This method does not require calibration because the phase-related adjustment factors for staffing requirements that are present in method 1 are not required here. Those factors are present in method 1 to adjust the slope of the progress profile based on the project phase because the user does not provide a progress profile to be followed. However, since in method 2 the user provides the progress profile, no adjustment factors are needed since the model uses the progress factor and the slope factor. As such, stage 4 of calibration is not needed if method 2 of the staffing module is used.

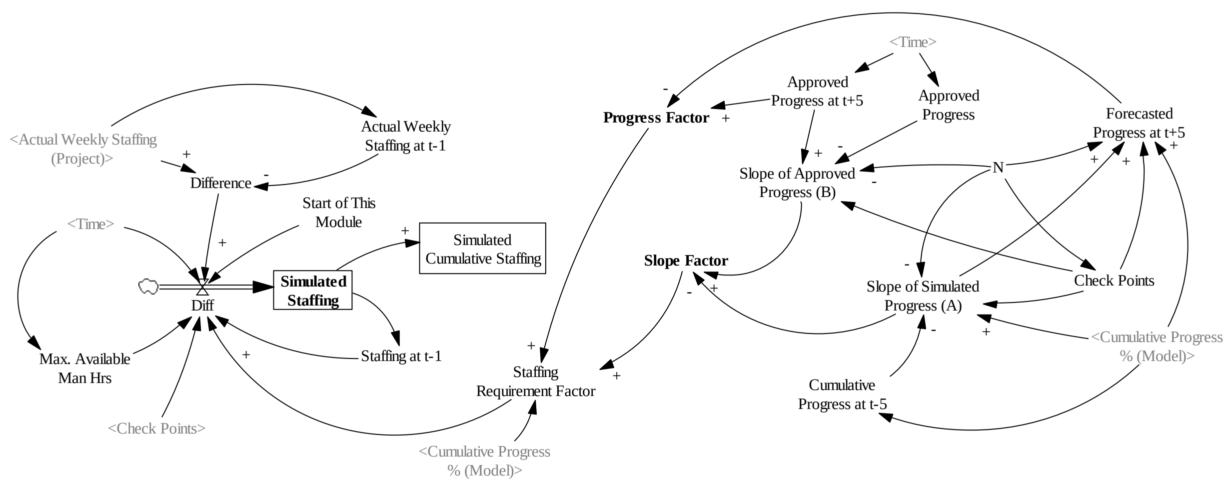


Figure 4.14. The Model's Staffing Module – Method 2.

Similar to the disruption module, the staffing module with its two methods is unique to this model and has not been developed in other relevant construction dynamic modeling research. The rest of the mathematical equations is provided in Appendix E.

4.6.5 Staffing Distribution Module

This module is responsible for distributing the available units of staff among the initial completion, QA, and rework types of work. However, determining the overall staffing requirement is the function of the staffing module, not this one. In short, the staffing module determines the staffing requirements based on comparisons between forecasts and actual progress, and the staffing distribution module - this module - distributes such units of staff among the different departments. This module does not only take its staffing inputs from the staffing module. Depending on the different model calibration stages, the sources of staffing vary. Other sources of staffing include the actual weekly staffing and the planned weekly staffing. Determining which staffing input to use in which calibration stage is discussed in the model calibration section. Figure 4.15 shows the staffing distribution module taking its staffing input named “simulated staffing” from the staffing module.

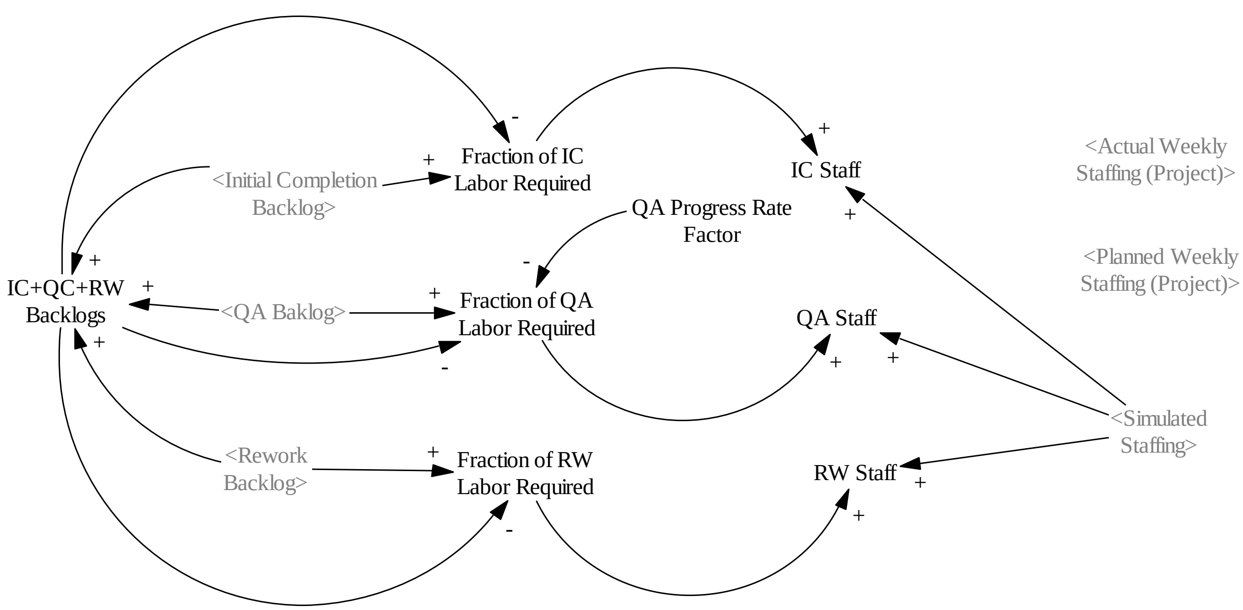


Figure 4.15. The Model’s Staffing Module.

As shown in Figure 4.15, at any given time, the fraction of staff that is allocated to work on a certain backlog is determined by the amount of remaining work units relevant to the rest of the remaining work units in the rest of the backlogs based on the following equations:

$$Fraction\ of\ IC\ Labor\ Required_t = \frac{IC\ Backlog_t}{IC + QC + RW\ Backlogs_t} \quad \text{Eq. (4.24)}$$

$$Fraction\ of\ RW\ Labor\ Required_t = \frac{RW\ Backlog_t}{IC + QC + RW\ Backlogs_t} \quad \text{Eq. (4.25)}$$

$$Fraction\ of\ QA\ Labor\ Required_t = \frac{QA\ Backlog_t}{IC + QC + RW\ Backlogs_t} \times QA\ Progress\ Rate\ Factor \quad \text{Eq. (4.26)}$$

The amount of staff of any type is the fraction of that staff multiplied by the staffing source; which is the "simulated staffing" in Figure 4.15. To complete a work unit, the worker takes a certain amount of time. However, to review the work unit and check its quality after it is performed, the QA staff takes less time. This ratio of productivity between the IC staff and the QA is represented by the variable named "QA progress rate factor".

4.6.6 Disruption Module

Figure 4.16 shows the causal diagram forming the disruption module. As the amount of OOS work increases, the "fraction discovered to require change" increases; meaning that a lower percentage of work is approved by the QA staff due to unacceptable quality. This magnitude of that impact is determined by the variables named "planned IC staff quality of work" (A) and "impact of OOS on quality" (B); where (A) is the normally planned error rate made by construction workers. (A) is obtained from the project planners and (B) is determined by the model during the multi-stage calibration process (Section 4.7). For example, if a company plans that 2% of the work will be repeated due to errors of the construction workers, then the variable (A) would have a value of 0.98. The variable (B) represents the relationship between OOS and defective construction work where 0 indicates no relationship and 1 indicates strong relationship. The same arrangement is used for the relationship between OOS and the errors by the QA staff, shown in Figure 4.16 as variables "QA effectiveness factor", "planned QA effectiveness factor" (D), and "Impact of OOS on QA effectiveness" (E). (D) is obtained from the project planners and (E) is determined by the model during the multi-stage calibration process. The discussed variables cover the impact of OOS on quality in general. This relationship also draws an indirect relationship with the overall progress rate and the staffing requirements since lower quality means more rework, more rework means lower overall productivity, which leads to higher staffing requirements and higher costs. The equations relating the discussed variables are as follows:

$$Fraction\ Discovered\ to\ Require\ Change_t = 1 - \left(\left(1 - (B \times Percentage\ of\ OOS\ Work_t)\right) \times A\right) \quad \text{Eq. (4.27)}$$

$$QA\ Effectiveness\ Factor_t = \left(1 - (Percentage\ of\ OOS\ Work_t \times E)\right) \times D \quad \text{Eq. (4.28)}$$

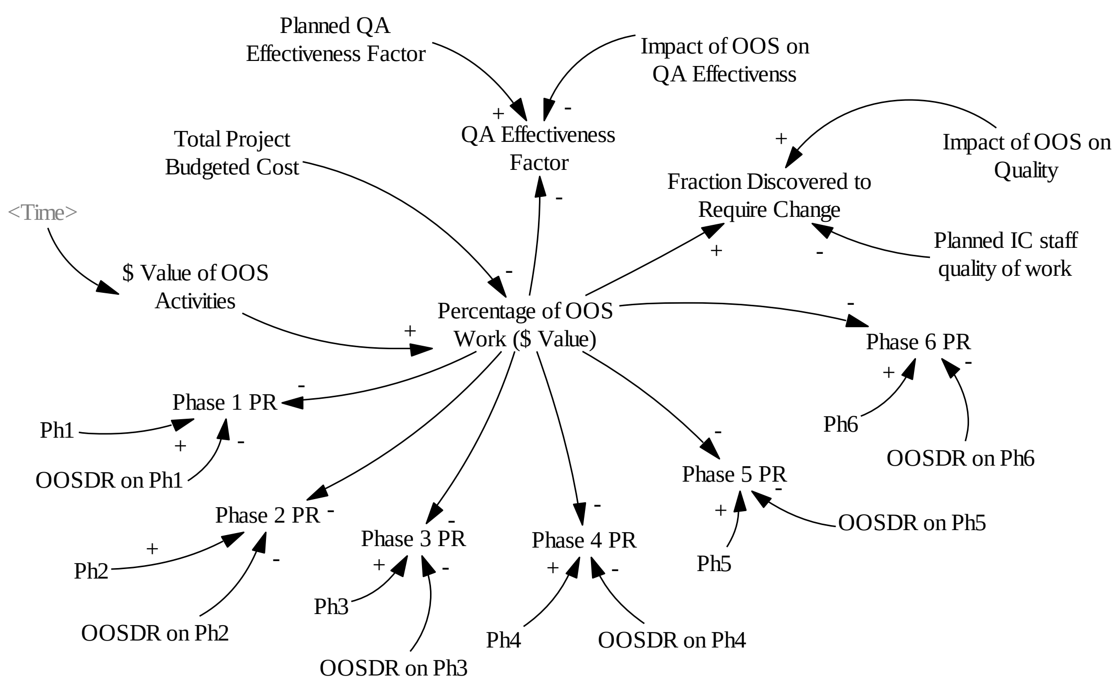


Figure 4.16. The Model's Disruption Module.

As mentioned in the Progress Rate module, variables named "Phase [Number] PR" represent coefficients for the differential progress rates at the different project phases. Each of these variables is a function of three variables; namely "Ph[Number]", "OOSDR on Ph[Number]", and "OOS percentage", as shown in Figure 4.16. This function is presented in Equation 4.29.

$$Phase\ \#\ PR\ =\ (1 - (OOSDR\ on\ Ph\#\ \times\ OOL\ Percentage\ )) \times Ph\# \qquad \text{Eq. (4.29)}$$

The variables “Ph[Number]” represent the planned stage progress rate coefficients assuming the project goes without disruptions. They are also referred to as “progress rate differentials” in this paper. Values of these variables are obtained through the first stage of calibration as will be discussed in the calibration section. The variables named “OOSDR on Ph[Number]” represent the relationship between OOS activities and the decline in progress rate. In other words, it embodies the effect of disruption on productivity in the sense of the undertaken modeling approach. A value of zero means no effect. A positive number means lower progress rate with higher OOS percentage. A negative value means higher progress rate with higher OOS percentage. Since there are multiple phases in the project, each stage behaves differently towards disruption. That is why there are multiple “OOSDR on Ph[Number]” variables; one for each project phase. As such, this grasps the dynamic impact of the project’s reaction towards disruption. The values of the variables “OOSDR on Ph[Number]” are obtained at stage 3 of the calibration process, as explained in the Calibration section of the paper. The variable named “Total Project Budgeted Cost” is a single number, and its name is self-explanatory. It is obtained from the project planners. The variable named “$ Value of OOS Activities” is a time-dependent variable that is changing over time. It shows the total value of all OOS activities taking place at time *t*. This variable is also obtained from the project planners.

4.6.7 Interaction among Modules

All of the discussed modules are inter-connected and work simultaneously; meaning that variables that are considered exogenous to certain modules are endogenous to other modules. Since it was impossible to plot all of the modules in one figure to show the inter-connections, the stock and flow figure was provided for each of the modules was separately, where the grey variables in each of Figures 4.9, 4.11, 4.12, 4.14, 4.15, and 4.16 represented variables that are imported from modules other than the one that the figure describes. For example, in Figure 4.15 representing the Staffing Module, the input variable named “QA Backlog” is colored grey because it is considered an output variable from the Workflow Module (Figure 4.9). In other words, the grey variables represent are the ones that connect between the different modules. To demonstrate the inter-connectivity among the different modules, Figure 4.17 was developed; which shows the input and output variables in each module. In figure 4.17, some variables are repeated in multiple modules. Those variables are considered output variables in their modules if they have the circular symbol in front of them and input variables in their modules if they have the arrow head pointing at them.

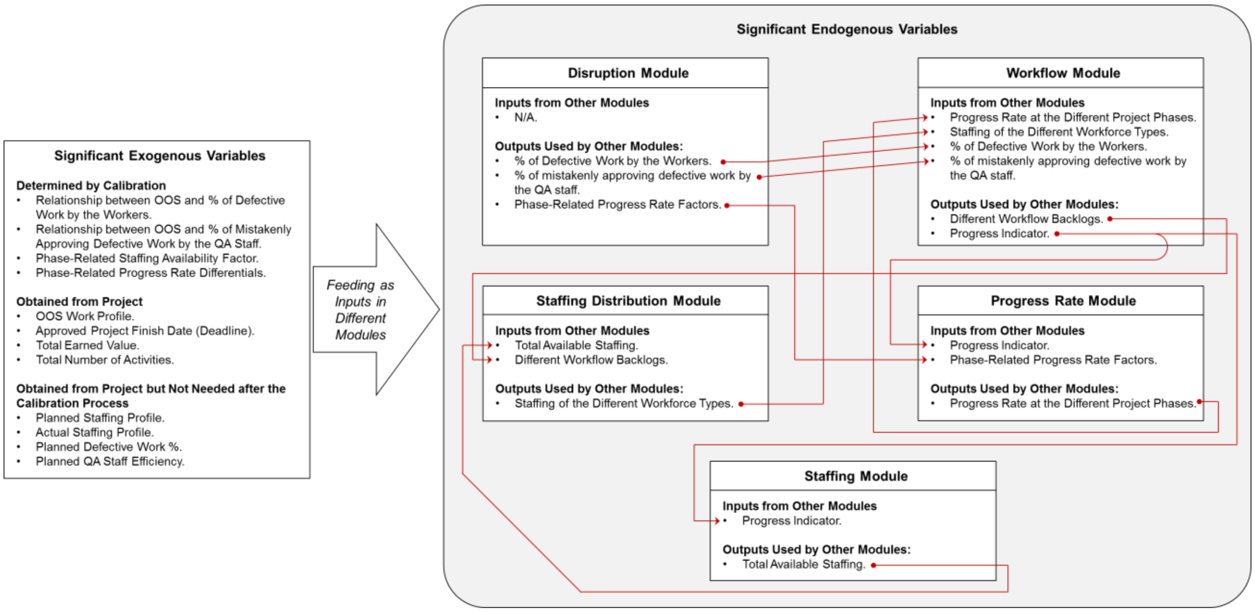


Figure 4.17. Inter-Connectivity of the Different Modules.

4.7 Multi-Stage Calibration Heuristic

After developing the different modules in the simulation model, a multi-stage calibration heuristic is developed. Calibration is the process of estimating the model parameters (structure) to obtain a match between observed and simulated structures and behaviors (Oliva 2003). Confidence that the built SD structure, with reasonable parameter values, is a valid representation increases if the structure is capable of generating the observed behavior. If the structure fails to match the observed behavior, then it can certainly be rejected; meaning that the causal relationships in the stock-flow diagram are erroneous from the first place and have to be reconstructed. As such, calibration is the key determinant to the model's success.

Generally, in each SD model, the different variables impact each other; hence the complex nature. However, there are some variables, also known as parameters, are exogenous to the model;

meaning that they are not affected by any of the other variables in the model but they affect others. The model calibration is performed through adjusting the values of the different *C* parameters until reaching the optimum ones that result in a simulated behavior that matches the one in reality. The initial parameter values for a SD model are normally estimate a priori from direct observations, educated guesses, and other sources of data (Oliva 2003). The final estimates of such parameters are obtained via calibration. As such, calibration becomes an optimization problem, adjusting the system parameters (*C*), to minimize a function of the differences between available data series (*A*) and the corresponding model output (*S*). A calibrated model is a model that is able to simulate the project's behavior to an acceptable level of accuracy. As such, a change in any parameter in a what-if scenario would yield a true change of behavior.

Calibrating all input variables associated with C (i.e. system parameters) at once in the developed model will not yield reliable results. This is because an optimization endeavor with several variables has a wide search space; which makes it hard for the optimization algorithm to find optimal solutions. This is why a novel multi-stage calibration methodology for breaking the optimization problem into four smaller optimization problems was devised.

The following sub-sections describe the variables and objective function of the optimization problem in each calibration stage. Before that, it should be mentioned that the used software for developing the model and performing the calibration is Vensim® software of Ventana Systems, Inc, Harvard, MA. Vensim® uses modified Powell hill climbing algorithm for optimization (Ventana Systems Inc. 2017). The listed calibration procedure is for almost all projects, and it serves the purpose of the study. If other modules are added to the model, then the calibration procedure would undergo changes by either adding calibration stages, modifying existing ones, and/or changing the order of the stages. Each calibration has its own input variables and objective function(s). The values of these input variables will be different in each project; and are obtained through the calibration process, not from the project data. Once the model is calibrated to a project, its results will be specific to that project. However, it can be re-calibrated again to any other project by running the calibration procedure and obtaining new values for the input parameters.

4.7.1 Calibrating Stage 1

In this stage, the objective is to make the model replicate the planned progress given the planned staffing. At this stage, the OOS work is set to zero because it is assumed that projects do not plan for OOS work. The variables "IC Staff", "QA Staff", and "Rework (RW) Staff" in Figure 4.15 would be connected to "Planned Weekly Staffing (Project)". The optimization variables are the progress rate differentials of the different project phases, which are those named "Ph[Number]" in Figure 4.16. The objective function is to minimize the square error between the planned and simulated progress as follows:

$$Minimize \sum_{t=0}^{T_p} (PCEV_t - SCEV_t)^2 \qquad \text{Eq. (4.30)}$$

Where, $PCEV_t$: Planned Cumulative Earned Value at time t

$SCEV_t$: Simulated Cumulative Earned Value at time t

T_P: The week number at which the project is planned to finish

4.7.2 Calibrating Stage 2

After being able to replicate the planned behavior in stage 1 of the calibration, the objective of stage 2 is to enable the model to replicate part of the actual behavior given the actual staffing. At this stage, the actual percentage of OOS work is used, either percent value or percent number of activities. The variables "IC Staff", "QA Staff", and "RW Staff" in Figure 4.15 would be connected to "Actual Weekly Staffing (Project)". The optimization variables are "Impact of OOS on QA effectiveness" and "Impact of OOS on Quality" in Figure 4.16. This stage calibrates the actual project behavior only from the angle of quality and rework. As such, the variables representing the relationship between OOS activities and the decline in progress, which are named "OOSDR on Ph[Number]" in Figure 4.16, are set to zero in this stage. Continuing the calibration to cover the actual progress rate is carried out in Stage 3 of the calibration. The objective function is as follows for stage 2:

$$Minimize \sum_{t=0}^{T_A}(ARQA_t - SRIC_t)^2 + (ARQA_t - SRIC_t)^2 \qquad \text{Eq. (4.31)}$$

Where, $ARQA_t$: Actual Rework Due to QA Staff Mistakenly Approving Defective Work at time t

$SRQA_t$: Simulated Rework Due to QA Staff Mistakenly Approving Defective Work at time t

$ARIC_t$: Actual Rework Due to Defective Work by Initial Completion Staff (laborers) at time t

$SRIC_t$: Simulated Rework Due to Defective Work by Initial Completion Staff (laborers) at time t

T_A: The week number at which the project was actually completed.

4.7.3 Calibrating Stage 3

The objective of stage 3 is to enable the model to replicate the full actual behavior given the actual staffing. All inputs and connections at this stage is similar to those of stage2 except that at this stage, the optimization variables are those representing the relationship between the magnitude of OOS activities and the decline in progress, which are named "OOSDR on Ph[Number]" in Figure 4.16. Also, the values in the variables named "Impact of OOS on QA effectiveness" and "Impact of OOS on Quality" in Figure 4.16 are those obtained from stage 2 (these two variables were the optimization variables in stage 2). After calibrating stage 3, the model is able to replicate both planned and actual behavior of the project. However, it is not able yet to simulate its own staffing based on the project parameters. The staffing has to be fed to the model. The objective function is to minimize the square error between the actual and simulated progress as follows:

$$Minimize \sum_{t=0}^{T_A}(ACEV_t - SCEV_t)^2 \qquad \text{Eq. (4.32)}$$

Where, $ACEV_t$: Actual Cumulative Earned Value at time t

$SCEV_t$: Simulated Cumulative Earned Value at time t

T_A: The week number at which the project was actually completed.

4.7.4 Calibrating Stage 4

After this final stage of calibration, the model is able to generate its own staffing and replicate all project parameters on its own in terms of staffing, progress rates, and quality. As such, users could input their different disruption scenarios and the model will be able to provide the corresponding behavior; thus, enabling users to test different policies and run sensitivity analysis to quantify the different direct and indirect impacts of disruptions. In this stage, the variables "IC Staff", "QA Staff", and "RW Staff" in Figure 4.15 would be connected to "Simulate Staffing". The obtained values of the different optimization variables in the previous three calibration stages are used. The optimization variables in this stage are the phase-related adjustment factors for staffing requirements, named "Cor. Ph#" in Figure 4.12. The objective function is to minimize the square error between 1) the actual and simulated progress, and 2) the actual and simulated staffing as follows:

$$Minimize \sum_{t=0}^{T_A}(ACEV_t - SCEV_t)^2 + (ACS_t - SCS_t)^2 \qquad \text{Eq. (4.33)}$$

Where,

$ACEV_t$: Actual Cumulative Earned Value at time t

$SCEV_t$: Simulated Cumulative Earned Value at time t

ACS_t: Actual Cumulative Staffing (Man-hrs) at time t

SCS_t: Simulated Cumulative Staffing (Man-hrs) at time t

T_A: The week number at which the project was actually completed.

This calibration stage is not needed if the user is using method 2 of the staffing module.

4.7.5 Evaluating the Calibration

The calibration procedure is as follows: The calibration stages should be undertaken sequentially. After each calibration stage, the simulation behavior (model output S) and the project behavior (data series P) at every point in time t need to be compared quantitatively to determine whether the calibration was successful. Among the most common measures are the coefficient of determination R^2 and Theil's Inequality Coefficient U as mentioned in Sterman (2000). These measures have been used in other relevant SD works such as Li and Taylor (2014). R^2 measures the fraction of the variance in the data explained by the model. It ranges from 0 to 1; where $R^2 = 1$ if S exactly replicated P. The value of U also ranges between 0 and 1. A value of 0 indicates perfect match of S and P and 1 indicates that S is no better than a naïve guess (Li and Taylor 2014). Stephan (1992) considers that a model with U under 0.4 is considered a good fit. However, to provide better accuracy, we propose that the value of U should be under 0.1 for the calibration at any stage to be considered successful.

The mathematical formulation of the coefficient of determination R^2 as obtained from Sterman (2000) is shown in Equation 4.34. The mathematical formulation of Theil's Inequality Coefficient U as obtained from Li and Taylor (2014) is shown in Equation 4.35.

$$R^2 = r^2, \qquad r = \frac{1}{n}\sum_{t=1}^{n} \frac{(P_t - \overline{P_t})(S_t - \overline{S_t})}{\sqrt{\sum_{t=1}^{n}(P_t - \overline{P_t})^2 \sum_{t=1}^{n}(S_t - \overline{S_t})^2}} \qquad \text{Eq. (4.34)}$$

$$U = \frac{\sqrt{\frac{1}{n}\sum_{t=1}^{n}(S_t - P_t)^2}}{\sqrt{\frac{1}{n}\sum_{t=1}^{n} {S_t}^2} + \sqrt{\frac{1}{n}\sum_{t=1}^{n} {P_t}^2}} \qquad \text{Eq. (4.35)}$$

Sterman (2000) indicates that because of the measurement errors, abstractions, aggregation, and simplifications, exact calibration of SD models is impossible. Rather, the verification tests and calibration evaluation demonstrate the model's usefulness by revealing some its capabilities, limitations, and flaws to assist prospective model users in properly applying the model to their applications.

4.8 Model Verification

Model verification is an essential step prior to drawing any conclusions or making any inferences. Verification ensures that the developed model properly represents the adopted theory. It also ensures that the model meets the required specifications and produces the expected behavior with no numerical or behavioral errors resulting from inadequate dynamic hypothesis or equation typos.

The expected behavior is obtained from data from the studied projects, data from other projects, and experience of the professional administrating the model. For example, it is expected that by starting the project with a larger number of experienced design engineers, the design stage would be shorter. If the number of experienced design engineers in the model is increased and the duration of the design stages got longer, then the model did not produce the expected behavior and needs to be modified. Of course, some elements are difficult to expect, such as adding in-experienced engineers. In this case, two different micro-behaviors will take place. The first is an increase in the design productivity due to the increased number of engineers, and the second is a decline in the design productivity due to the fact that there is a wasted time in training them by the experienced engineers. In this case, the model is considered valid if it was able to capture both micro-behaviors. The final behavior of the model would be compared to the project's behavior in the calibration process. When calibrated, all micro- and macro-behaviors in the model should be matching the project's micro- and macro-behaviors.

Sterman (2000) provides comprehensive methodologies for verifying SD models. These methodologies are in the form of verification tests that are widely used by SD modelers. Table 4.5 shows Sterman's verification tests and how they apply to the proposed model. If any verification test fails, this means that the dynamic hypothesis or the detailed stock and flow diagrams have incorrect relationships. In this case, the model needs to be re-structured and tested again, until it passes all of the verification tests. It should be noted that the model at its current form passed all of the verification tests in Table 4.5.

Table 4.5. Model Verification Tests.

Verification Test	To Answer this Question
Boundary Adequacy	• Are the important concepts for addressing the problem included in the model?
Structure Assessment	• Is the model structure consistent with the relevant declarative knowledge of the system?
Dimensional Consistency	• Is each equation dimensionally consistent without the need of variables having no real world meaning?
Parameter Assessment	• Are parameter values consistent with relevant aspects of the system?
Extreme Conditions	• Does the model respond reasonably when subjected to extreme conditions (input parameters)?
Integration Error	• How sensitive is the model to different time steps and integration methods?
Behavior Reproduction	• Does the model generate the behavior of interest in the system?

4.9 Model Discussion

4.9.1 Model Information

The complex system described in the previous sub-sections has been developed in the form of a SD model in Vensim® software of Ventana Systems, Inc, Harvard, MA. based on the model boundary and level of aggregation shown in Figures 4.9, 4.11, 4.12, 4.14, 4.15, and 4.16. Due to the comprehensive level of details, the model used is rather large and its details cannot be fully explained in depth in the paper. That is why the we have supplied the detailed mathematical formulations in Appendix E to enable reproducibility and ease of access to interested researchers.

4.9.2 Validation

When a model passes all validation tests and is calibrated to a project (i.e. being able to replicate the planned and actual conditions of that project), then it is said that this model is validated (Barlas 1996, Godlewski 2012). Even with that, "*a model cannot have absolute validity but it should be valid for the purpose for which it is constructed*" (Martis 2006). In the case of this research, the purpose of the model is to grasp how OOS work impacts project progress. The model was developed, verified, and calibrated to a case study (that is discussed at the end of the paper). Of course, no model is complete or perfect (Sterman 2002). However, the model was able to replicate the project conditions of the case study with high accuracy, and the received feedback indicated usefulness in grasping the dynamics of OOS work and applicability in the industry. Thus, the model is considered validated to that project and similar projects. Other projects might have different conditions that require structural changes in the model. This does not negate the validity of the model.

4.9.3 Limitations and Areas for Future Enhancements

It should be mentioned that the model does not take the engineering phase into account. It only considers interruptions in the construction phase. However, a strong advantage in the developed model is that it is modular; meaning that users can add modules to it. For example, they could consider the effect of working overtime on productivity by adding the concepts of Alvanchi et al

(2012). They also could incorporate the effect of engineering rework by adding the associated concepts and findings of Li and Taylor (2014).

It should also be noted that the term "flow" is not necessarily equivalent to flow in lean construction (e.g. production flow and work flow). In SD, a flow means the variable controlling the speed at which the stock increases or decreases. For example, if a stock represents the available number of design engineers, the outflow could be the rate of turnover and the inflow could be the hiring rate. This does not negate the fact the SD is a highly applicable tool for better understanding and modeling lean construction. For example. Ko and Chung (2014) developed a lean design process to enhance design reliability and validated it using SD. The number of studies utilizing SD in lean construction is expected to increase, especially after Sacks et al. (2017) have defined an index for construction flow. Such index could be incorporated in SD future models for managers to be able to monitor the production flow quality in their projects and understand how the different project conditions impact it. This could also provide deeper insights on production flow and how to enhance it by complementing the works of Sacks (2016) with SD modeling.

Another area of development is using the developed model to study the impact of variability of certain parameters on performance. The developed model looks at the construction work flow from a macroscopic view based on the provided data and to serve the purpose of the research. Future research is encouraged to add some microscopic elements such as modeling the flow of work of several types of crews rather than just on macroscopic work flow, and to add stochastic capabilities to model variability. Although the effect of work flow variability on trade performance has been studied by Tommelein et al (1999) and Hopp and Spearman (2011), its incorporation in SD models and its relationship with OOS work has not been investigated yet. Speaking of variability and stochastic elements, uncertainty could be added to SD models; thus, having the potential to be complementing to Program Evaluation and Review Technique (PERT) and Graphical Evaluation and Review Technique (GERT) analyses. This combination has not been achieved before in construction research.

4.10 Case Study

After the model is developed as per the dynamic hypotheses associated with the five modules and verified as per the tests highlighted in Table 4.5, it was applied to a real construction project to demonstrate some of its capabilities and validate its applicability. The project is described as a 37-story building containing luxury residential units, a five-star hotel, and a convention center. Execution was planned to take 280 weeks with a budgeted value of $486,314,357. The project encountered major OOS work caused by several attributes such as scope changes and changes in the execution plan. This resulted in delays, productivity loss, cost increase, and quality decline that is reflected in rework rates higher than planned. When the project data was collected, the project was in week 306 and the progress was only 82.3%. According to forecasts made by the project's planning team, the project will end at week 393; which is 113 weeks more than the planned duration. As per the confidentiality agreement with the information provider, the name of the project is not mentioned in the paper. However, it was allowed to share the project's anonymous data that is used in the developed model to researchers by request. The inter-relationships and math in the model's modules were discussed with the project's senior engineer who provided the data to ensure applicability. The following data was gathered from the project:

- Planned and actual earned value,
- Planned and actual man-hours,
- Planned and actual value of rejected work and accepted work that has been approved by mistake,
- OOS activities and the time and duration of their occurrence,
- Master baseline schedule (planned) and updated schedule (actual),
- Times and durations of the different project phases,
- Values and times of added scope (if any), and
- Times and durations of any stoppages due to external events (if any).

The developed SD model was calibrated to the project using the 4-stage calibration methodology. The model was able to successfully replicate the project's planned and actual behavior (Figure 4.18). In the figure, it could be seen that there are no significant differences between the model and the project. It could be also confirmed numerically since the inequality coefficient U is always less than 0.1 and the coefficient of determination R^2 is always higher than 0.99. Multiple scenarios were run to analyze the behavior of the project under different conditions. Each group of scenarios are discussed collectively because usually the difference between the scenarios in each group would be in one parameter. So, each group of scenarios provides a sort of sensitivity analysis to a certain parameter as discussed in the following sub-sections.

4.10.1 The Effect of the Staffing Availability on the Project

Four scenarios were modeled in this group. The only difference among these scenarios is the number of maximum available staff that the project has at any point in time. Part A of Figure 4.19 shows the planned conditions and the corresponding weekly staffing. In such conditions, there was no OOS work. The corresponding total man hours invested in the project is 19,693,958. Scenario 1 mimics the same planned conditions in terms of the desired progress and maximum available staffing; where the project is supposed to end in 280 weeks and the availability of staff is shown in the dotted line in part B of Figure 4.19 (150,000 man-hours per week in some weeks, 75,000 man-hours per week in other weeks, and so on). The only difference between this scenario and the planned conditions in that in this scenario there is OOS work. The profile of OOS work is shown part F of the figure. As such, this scenario answers the following question: *What if OOS work took place and the management did not take any actions regarding adjusting the maximum available staffing and changing the project's finish time?* The result of this non-flexibility is that the project used its maximum available staffing in most of its course; which led to investing a total of 25,703,175 man-hours. This is 30% higher than the planned total man-hours. As such, additional costs are incurred. Not only this, the available staffing was not sufficient to finish the project on time so the project took 301 weeks rather than the planned 280 weeks as shown in part F of Figure 4.19.

The OOS work and the desired progress profile for scenarios 1, 2, 3, and 4 is the same. The only difference among these scenarios is the maximum available weekly staff. For scenario 2, a maximum of 150,000 man-hours was used all over the project. This is different than the planned maximum weekly staffing in the sense that it is constant and that it higher than the planned in some weeks and lower than it in other weeks. The resulting total man hours is 23,485,656 and the

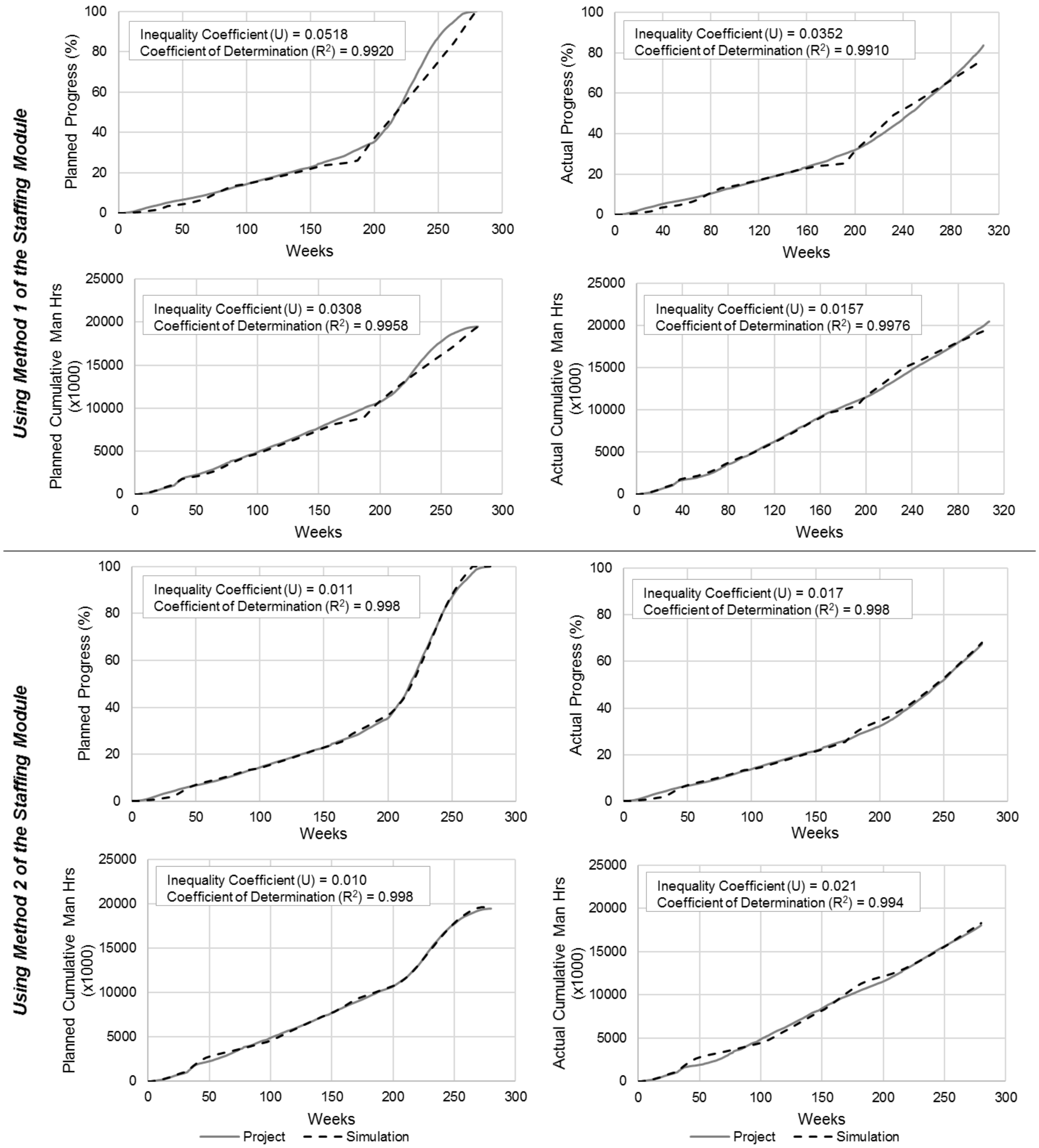


Figure 4.18. Model’s Ability to Replicate the Planned and Actual Project Circumstances.

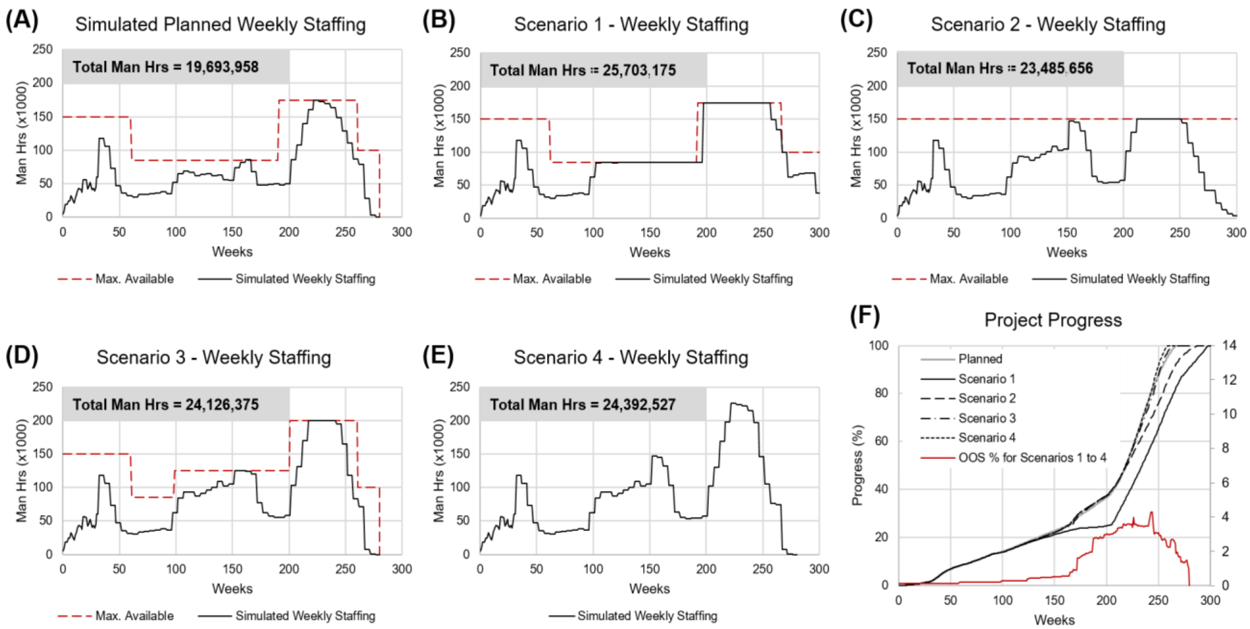


Figure 4.19. What-if Scenarios Demonstrating the Effect of Staffing on the Project.

project's simulated finish date is week 291. Although this finish time is higher than those of scenarios 3 and 4, it resulted in the least total man-hours among these scenarios. As such, a delay in time does not necessary mean an increase in the total man-hours. This demonstrates the model's capability in capturing this complex and non-linear relationship between total man-hours and project duration. In scenario 3, the maximum available staffing is similar to that of the planned conditions until week 100; after week 100, the maximum available staffing in the scenario is higher than that in the planned conditions. This is because the OOS work started to have an effect after week 100, so there was no need to make changes before that. In this scenario, the project was able to finish on time, but with higher total man-hours. In scenario 4, it was assumed that there was unlimited amount of available staff at any point in time. This scenario was made to answer the question of: Given the current OOS work, what would be the required staffing for the project at any point in time? By answering this question, the management would be able to determine the required staffing each week and compare that to their actual resources so that they would study ways to make proper adjustments.

4.10.2 The Effect of Timing of the OOS Work on the Project

Two scenarios – scenarios 4 and 5 - were compared to demonstrate the effect of the timing of the OOS work on the project. In both scenarios, the total value of activities performed out of sequence is 21.4; which resembles the actual project conditions. In both scenarios, the desired finish time was 280 days and the desired progress profile was that of the planned conditions. Also, the maximum available number of man-hours per week is 300,000 in both scenarios, which is a very high number relevant to the planned and even the actual project conditions. This large number is used to give the model the freedom to assign the required staff assuming almost unlimited resources to observe what would the project needs be. The only difference between the two scenarios is that the OOS happens at a late stage in scenario 4 and at an early stage as shown in the left side of Figure 4.20. The result of changing the timing of OOS work is significant. In scenario 4, the project never reached the 300,000 weekly man-hours limit; while in scenario 5, the project used this limit in 85 of the 180 weeks of the project as shown in the middle part of Figure 4.20. This resulted in investing a total of 40,594,840 man-hours in the project as shown in the right side of Figure 14; which is 66.4% more man-hours than scenario 4 and 106.1% more man-hours than planned. As such, in this project, having OOS early on without having any measures to minimize it or even relax the project's finish time has severe consequences. In the coming sub-section, we demonstrate how relaxing the project's approved finish time could be one of the beneficial solutions to minimize the rippled impacts of OOS.

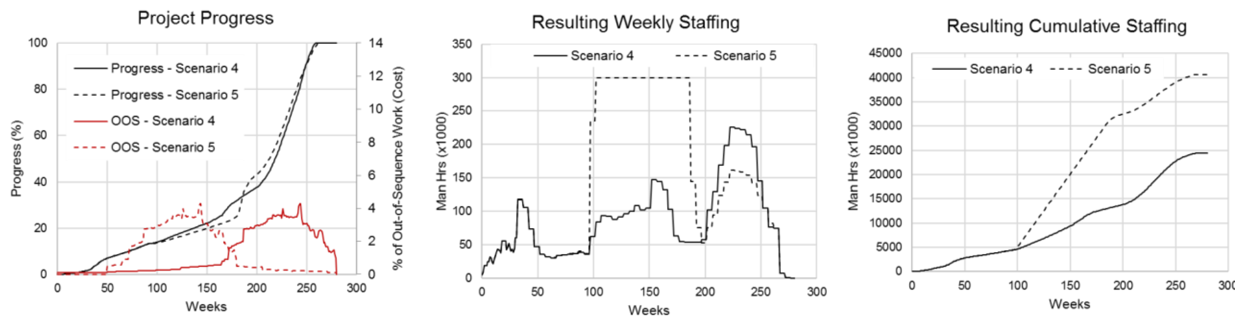


Figure 4.20. What-if Scenarios Demonstrating the Effect of OOS Timing on the Project.

4.10.3 The Effect of Relaxing the Approved Finish Date on the Project

Scenarios 6 and 7 have the same OOS work as scenario 5; in the sense that such disruptions were at the middle of the project rather than the end. In these scenarios, the limit of maximum available weekly man hours was set to 200,000. In scenario 6, it was assumed that the management were not flexible when the OOS took place and did not make changes to the approved planned progress; for which the project is supposed to end in 280 weeks. In scenario 7, it some flexibility was modeled in the sense that a new relaxed project progress was set so that the project ends in 310 weeks instead of 280. The simulation showed that at the time where the OOS events were significant, the project used all available man hours as shown in Figure 4.21. Since scenario 6 finished the project earlier, it used higher weekly man-hours but for a shorter duration than those of scenario 7. At the end, in both scenarios, the project invested almost the same total amount of man-hours. However, this should not be generalized. Other scenarios could show that relaxing the project's progress profile lead to more total man-hours and other scenarios could show the opposite. This is a strong advantage of the developed model; where it lets the users experiment for themselves the desired scenarios in details rather than providing empirical non-accurate conclusions.

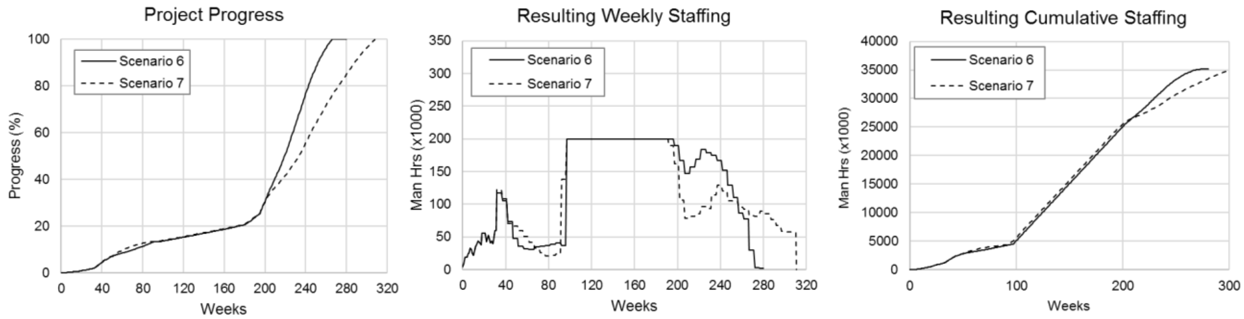


Figure 4.21. What-if Scenarios Demonstrating the Effect of Relaxing the Approved Finish Date on the Project.

4.10.4 What-if Scenarios Demonstrating the Other Non-Linear Relationships

The previous scenarios were ran using method 2 of the staffing module because the model was provided the desired approved project progress profile rather than just the approved finish time. The following scenarios were ran using method 1 of the staffing module; where the model was fed the desired finish time rather than the progress profile. The following scenarios are just for the purpose of demonstrating the model's ability to grasp the non-linear relationships between OOS work, rework, and staffing.

In scenario 8, the project encounters OOS activities relatively with the same distribution as the ones in the actual project but with less magnitude as shown in the left part of Figure 4.22. In this scenario, the approved deadline was assumed to be at week 315. In scenario 9, the deadline is strict at week 280 and the OOS activities were assumed to be with less value. This scenario models minor disruptions that are mitigated quickly by the management. In scenarios 10 and 11, it was assumed that the project encountered major disruptions that are concentrated in the middle of the project rather than at the end like the "Actual" scenario. In these scenarios, the management take measures to mitigate disruption but the effects of this mitigation plans did not take place until around week 220. In those scenarios, the deadline was set to week 280, however, if the project was not able to fulfil such deadline, it would change automatically to week 320 assuming. This simulates the management's decision to extend the time for completion. The only difference between both scenarios is that the maximum available man-hours at any week is 150,000 in scenario 10 and 250,000 in scenario 11. Table 4.6 and Figure 4.22 show the results. Although the project ended earlier in scenario 11 than it did in scenario 10, it used 109% more man-hours than planned while scenario 10 used 79% more. Both are high numbers. But this shows that at this project, using more man hours without relaxing the finish date is better than relaxing the finish date while having less weekly man hours.

Table 4.6. Scenarios 8 to 11.

	Planned	Actual	Scenario 8	Scenario 9	Scenario 10	Scenario 11
Total Value of OOS Activities	$0	$87,870,770	$40,153,393	$9,9137,386	$19,085,949	$19,085,949
Percent from Total Project Value	0%	21.4%	9.8%	2.2%	4.7%	4.7%
Rework resulting from False Approvals of QA Staff	0.1%	1.0%	0.52%	0.22%	0.26%	0.26%
Rework from Mistakes by Workers	1.0%	6.6%	3.45%	1.70%	1.94%	1.94%
Total Man Hrs (x1000)	19,503	N/A	20,315	20,467	35,015	40,746
Deviation from Planned Man Hrs	0	N/A	+4.2%	+4.9%	+79%	+109%

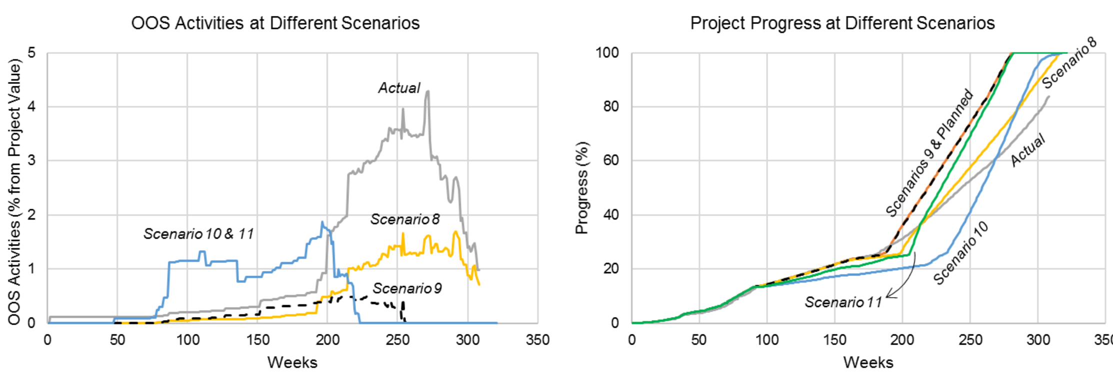


Figure 4.22. What-if Scenarios Demonstrating the Other Non-Linear Relationships.

Another interesting finding is that, although scenario 10 has around half the OOS that scenario A has, scenario 10 yielded more man hours than scenario 8. This is because in scenario 8, the OOS was concentrated near the project end while in scenario 10 the OOS was in the middle of the project; phase 3 to be exact. This phase was of high complexity because the concreting and rough finishes took place simultaneously in this phase. This is why the OOS work in this phase is more impactful. As such, it can be concluded that the total value of OOS is not representative for what the project will face. The distribution of the OOS and at which stage it occurs is a more solid measure.

The project's planning team were supportive in providing the needed information required for developing and validating the model. Since the project's planning team do not have experience in SD modeling, they were not enthusiastic about using the model at first; especially that the project was at its late stage when the model was developed. However, when shown the results and scenarios, the team acknowledged that the model grasped relationships that are not grasped using traditional methods. The team also acknowledged that the model provided insights that would have helped them understanding the impacts of OOS work and how to mitigate them; especially in the scenarios comparing between early and late occurrence of OOS work.

4.11 Dynamic Modeling Guidelines for Directing Future Research Towards Holistic Analysis - Conceptual Framework

The chapter concludes by presenting guidelines – including a conceptual framework - to proactively drive future research towards holistic management of today's complex construction projects. The paper does not present an advanced model. However, the paper presents helpful information and guidelines that act as the seed for future research in developing an advanced dynamic model for holistic management of construction projects. Building such model requires extensive work, especially in ensuring project-based results rather than just general behavior.

There are certain sequential steps for building any system dynamics model. The first step is identifying the problem and selecting the model boundaries; where the considered key variables and concepts are determined. The second step is forming the dynamic hypothesis in which the variables are mapped using causal loop diagrams to explain the complex interactions among the system's variables. The third step is formulating the simulation model by further developing the causal loop diagrams into stock-and-flow diagrams and representing the relationships through mathematical equations. The fourth step is verifying the model through well-known verification and robustness tests listed in Sterman (2000). The final step is calibrating the model to ensure that it has the ability to replicate the behavior of the project in hand. A model that accurately reproduces the project's behavior given its conditions has the ability to perform credible what-if scenarios and forensic analysis, and aid in policy design (Sterman 2000). Each of the mentioned steps is dependent on the preceding step.

4.11.1 Problem Articulation

The identified problem is the need for a model that is able to capture the complexities and interconnectivities of project processes. The model needs to grasp the direct, indirect, linear, non-linear, instant, and delayed impacts of the different policies and conditions. The first purpose of the model is to aid in managing and controlling project during execution by providing what-if scenarios that display holistic interactions and hence support enhanced and well-informed policy design. This will minimize unintentional costs and enhance project performance in general. The second purpose, or benefit, of the model is to be used in dispute resolution throughout its forensic analysis capabilities.

As for the key variables, the conducted meta-analysis of the literature enabled the identification of 25 dynamic inter-connected parameters that directly influence the performance of construction projects. These dynamic parameters, which are stated and explained in Table 4.3, are to be used as the key variables for the proposed system dynamics framework. A system dynamics model considering such parameters in their entirety is able to grasp the complexities of the managerial processes of construction projects to an unprecedented extent.

One additional benefit of the identified key variables is that researchers could evaluate the roundness, or holistic efficiency, by observing which of these key variables are considered in their models. As the number of considered key variables increases, the efficiency of the model increases and the model becomes more holistic.

4.11.2 Holistic Dynamic Hypothesis

After identifying the problem and the key variables of the desired model, a causal loop diagram demonstrating the relationships between such variables in a cause-effect manner should be developed. Such diagram represents the dynamic hypothesis of the model and is formed based on established theories in their related area of research and in accordance with the theoretical descriptions in the literature. The dynamic hypothesis must recognize the way projects work in the sense of the multiple feedback systems. The following paragraphs provide examples on the relationships and feedbacks between the different project systems that future research must consider.

For the resource management feedback for example, deciding whether to hire new staff or not, and the amount and type of staff to hire depends on the difference between the needed staff [9] and the available staff as well as the available budget. Good planning efforts result in availability of optimal resources during execution, minimizing the need for hiring or laying off personnel. It is essential to recognize that adding resources does not simply mean increasing the production rate. Less experienced staff have lower productivity than more experienced staff. Also, less experienced staff are more prone to errors during executing their tasks; whether their tasks are related to execution or quality assurance. Moreover, although enhancing the experience of personnel throughout training has positive impacts on productivity and error generation, it adds to the cost of the project. Also, the decision of whether to train the staff or not is dependent on the budget.

One important feedback loop is the one relating to schedule pressure. When delays take place [3], managers usually make the decision of schedule pressure, on which they decide on whether to add more staff, work overtime, or add shifts. Working overtime does not simply result in an increase in the daily productivity. Several studies have been made to quantify the impacts of worktime policies such overtime on productivity (Alvanchi et al. 2012, Han et al. 2012, Howick and Eden 2001). For example, working overtime for short durations increases the daily productivity. However, this relationship is not linear. The developed framework recognizes such non-linearity and incorporates the studies made in this area. Working overtime for prolonged durations results in fatigue and decline in morale; which in turn lead to increased absenteeism and turnover, errors in execution, rate of false approvals by the quality assurance staff [19], and out-of-sequence work. When such mistakes are discovered, they have to be reworked. This rework consumes funds from the contingency account since owners are not responsible for such rework as it is resulting from poor resource management policies. Not only does rework impact cost, it also causes reduces the overall production rate since the perceived progress becomes inconsistent with the actual progress. This then restarts the loop and requires managers to take further schedule pressure measures; which could be destructive to the project performance.

In cases of delay, managers also have the option to extend the project's approved time of completion and approve a new baseline schedule to minimize their out-of-sequence work. Approving a later time of completion minimizes the need for prolonged schedule pressure; thus, avoiding the vicious circle of rippled impacts. On the other supportive hand, minimizing or even eliminating out-of-sequence work will decrease the amount of rework.

The framework draws the attention to some key variables that have direct and indirect impacts on project performance. For example, with enhanced coordination between parties, less disruptions will take place and the project will run smoothly. Another factor that disrupts the project's workflow is the time taken by the owner/engineer to reply to inspection requests or requests for information. Instead of waiting for a long time for the owner/engineer to reply, contractors start work on other parts to ensure continuity of workflow. This jeopardizes the sequence and actually leads to disruption in case the owner/engineer rejects some of the work executed by the contractor. Enhanced coordination also minimizes mistakes in design and ensures proper scope definition; thus, minimizing changes resulting from design processes. The framework also realizes that more planning efforts, although might be costly, end up in optimal estimation of needed personnel from the beginning of the project, optimal budget allocation, less changes, and less disruptions to workflow.

A conceptual framework was created to summarize the above-mentioned relationships and feedbacks, and to represent them in a visual way. The framework is shown in Figure 4.23. Sources in the literature focus on some relationships and disregard others. The presented conceptual framework acts as the first attempt to: (1) identify all key variables that define and control project performance, and (2) integrate all of them in a single figure. In the figure, arrows represent causal relationships between variables. The symbol "+" resembles a directly proportional relationship. This relationship could be linear or non-linear, but such relationship always has a positive slope. The symbol "-" resembles an indirectly proportional relationship between the connected variables; where also such relationship could be linear or non-linear. Finally, the symbol "#" resembles a nonlinear relationship that changed from "+" to "-" or the opposite with time or with different values of the causing variable. All relationships could be of instantaneous or delayed effects.

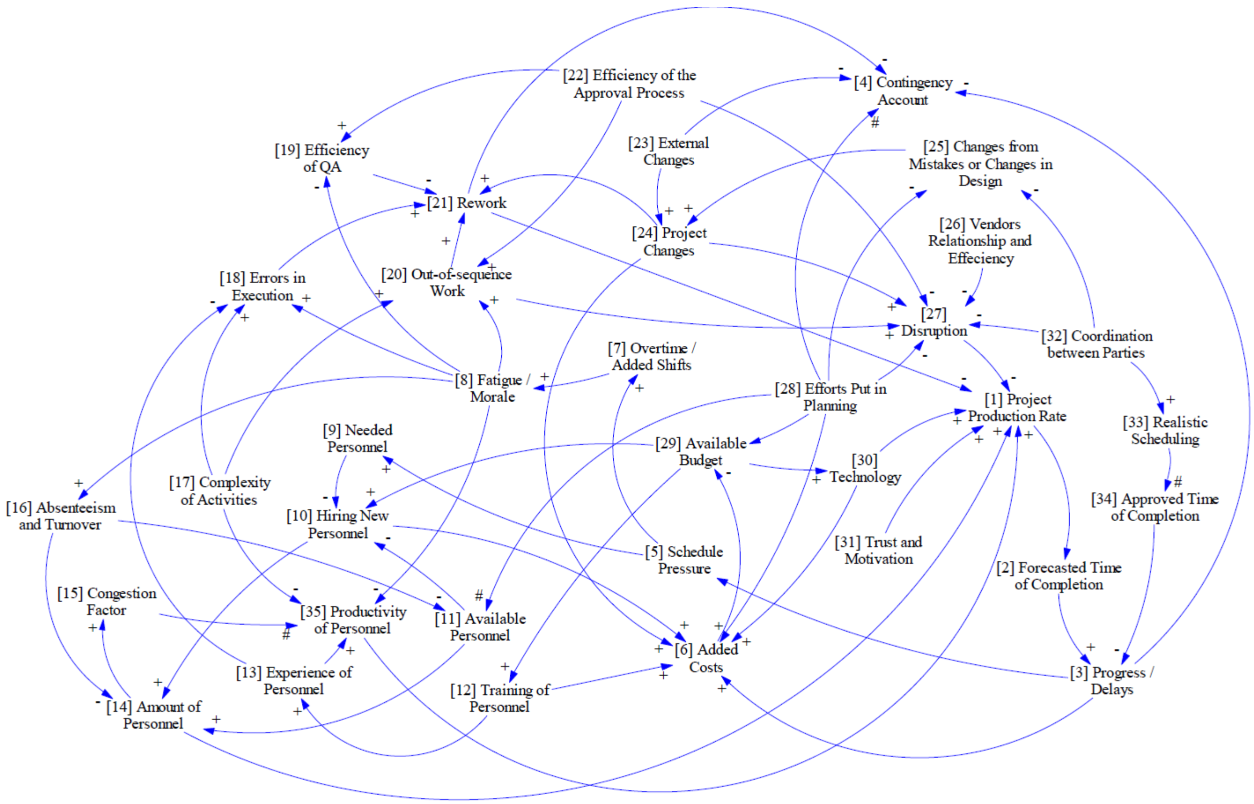


Figure 4.23. Proposed System Dynamics Framework for Holistic Management of Construction Projects.

Table 4.7 maps the key variables in the presented framework (Figure 4.23) with the 25 dynamic parameters that are identified by the meta-analysis of the literature. It can be seen that the presented conceptual framework takes all dynamic parameters into consideration.

4.12 Outcomes and How They Relate to Dispute Mitigation

Outcomes of this research help in: (1) understanding the relationship between OOS work and the different project feedback systems; (2) reasonably grasping rippled impacts of disruptions caused by OOS work, and (3) providing informative forensic analysis of the corresponding project overruns. If used in construction projects following the provided procedure, the developed model

Table 4.7. Mapping the Dynamic Parameters to the Variables in the Proposed Framework that is Shown in Figure 4.23.

Dynamic Parameters	Represented by Which Variables in the Proposed Framework?
P1: Realistic Scheduling	33
P2: Schedule Pressure	3, 5
P3: Complexity	17
P4: Coordination and Communication	32
P5: Efficiency of the Approval Process	22
P6: Trust and Motivation	31
P7: Ripple Effects of Schedule Pressure	8
P8: Productivity of Workforce	1, 35
P9: Constructability Reviews	28
P10: Resource Development	10, 12, 13
P11: Resource Allocation	10, 14
P12: Absenteeism and Turnover	16
P13: Workplace Congestion	15
P14: Overtime and Added Shifts	7
P15: Technology	30
P16: Rework in Execution	21
P17: Rework in Design	24, 25
P18: Reliability of Quality Assurance Staff	19, 22
P19: Out-of-Sequence Work	20, 27
P20: Controlled Change	24, 25, 27
P21: Uncontrolled Change	23, 24, 27
P22: Fabrication Quality	26
P23: Communication with Fabricators	26
P24: Financial Estimating	6, 29
P25: Budget Contingency	4

could be of significant help in resolving disputes by analyzing the different OOS work of the parties and determining the impacts caused by each party separately; thus, handling the blind spots of the traditional models that actually complicate the dispute resolution process. The model could be also used during the project for management and control. By enabling stakeholders to forecast the direct and indirect consequences of their policies, the model would aid them in making more informed decisions that will minimize the risk of disputes.

As for the intellectual merit, since the goal of this research has not been attempted before, it is expected to contribute significantly to the *construction management* body of knowledge as it: 1) acts as the first research effort to address and model the dynamics of OOS work; 2) enhances the understanding of how OOS work directly and indirectly impacts productivity, quality, and cost; 3) enables the quantification of such impacts; 4) models OOS work dynamically so that not only the magnitude of OOS but the timing of it as well impact the project; which mimics reality; 5) enables practitioners to perform different what-if scenarios to assess the effectiveness of their mitigation approaches and select the optimum one; 6) is modular in nature as mentioned earlier, so other researchers could build on it and expand its applicability, and 7) provides a multi-stage calibration methodology enabling practitioners to use it on almost any construction project and view results that are specifically tailored to such project for enhanced policy making.

The model also contributes to the *dynamic modeling* body of knowledge. The logic behind the multi-stage calibration methodology could benefit dynamic modelers in complex models since most SD models utilize single-stage calibration that limits the capabilities of models. Moreover, the staffing module provides advanced concepts that have not been used in this fashion even in the dynamic modeling community; thus, it could be of benefit to dynamic modelers who are involved in project management and resource management research.

4.13 Recommendations for Future Work

The entirety of sub-section 4.11 represents how future work is recommended to be directed. The developed SD model in the chapter fills critical voids such as incorporating OOS work in its analysis, and having an advanced staffing module that is able to set the staffing requirements autonomously to strengthen the modeling and scenario-making capability. Future researchers are recommended to utilize the developed model and integrate it with the other models in the literature to form a holistic model for project control and dispute analysis. In sub-section 4.11, guidelines are provided on how to form such a holistic model. Also, these guidelines are accompanied with a conceptual framework (Figure 4.23) that define the boundaries of what a holistic dynamic model should include. They guidelines and the conceptual framework collectively define the general feedback systems in a construction project and their interrelationships. Such holistic view has not been achieved before. As such, this will the scattered knowledge of the literature and provides a starting point for future research towards developing a major advanced model for holistic project management that would eventually revolutionize how construction projects are managed.

4.14 Related Appendices

Appendix E contains all of the equations and data used in the developed SD model and case study.

CHAPTER 5:
ANALYSIS OF OWNER'S OBLIGATIONS IN STANDARD FORMS OF DESIGN-BUILD CONTRACTS

5.1 Overview

Recent reports studying construction disputes in North America, Asia, the Middle East, and Europe have shown that poor contract administration is the most common cause of disputes (ARCADIS 2014, 2015). These reports are also supported by the findings of Colin et al (1996), Diekmann (1994), Sykes (1996), Yiu and Cheung (2006), and Waldron (2006) as they perceive poor contract administration by project parties as one of the major causes of disputes. Accordingly, proper contract administration is a leading factor in minimizing construction disputes.

Since the owner is the party in control of the finances, he sometimes overestimates his rights and underestimates his obligations, resulting in unjust actions towards the contractor. Understanding the owner's obligations conditions in construction contracts is vital. Failure to understand and administer such conditions, also known as "non-conformance" to the provisions, leads negative impacts on the parties' relationship and eventually on the project.

Owner's Obligations – Payment: The most important obligation for the owner is payment. It is a key factor of a project's successful completion. The performance of a project is directly correlated to uninterrupted funds (Ramachandra and Rotimi 2014, Cheng et al 2010). For example, the contractor's cash flow is greatly and negatively affected by delays in approving invoices, settling cost claims, settling payments and releasing retention moneys (Odeyinka et al 2008). From another angle, failure to abide by stipulated payment programme by owners lead to contractors incurring additional financing and transaction costs; which increases their risks of insolvency (Odeyinka et al 2005). Moreover, disregarding the insolvency that can be caused, this failure could have adverse impacts on the project such as degradation of quality and delays caused by intentional decrease of contractor's staff to minimize cost.

According to Chan and Suen (2005) and Kennedey (2006), irregular payments are one of the major causes of disputes in the construction industry. Moreover, payment and variation orders are found by Chan and Suen (2005) to be the top two areas of disputes in international construction projects. Also, according to Watts and Scrivener (1993), around 26% of total disputes are related to payment in Australia. In another country, New Zealand, disputes relating to payment between construction parties account for 80% of the cases (Ramachandra and Rotimi 2014). When it comes to project performance, based on the findings of Kartam and Kartam (2001), delayed payment is the second highest operational risk that causes project delays; with the first risk being financial failure. The following are <u>some examples of common payment problems</u> in construction projects (Sykes 1996, Kumaraswamy 1997, Cheung and Yiu 2006, Abidin 2007, and Ramachandra and Rotimi 2014):

- Non-payment of certified sums
- Delay in progress payments
- Valuation of final account
- Late release of retention money
- Valuation of variations
- Following erroneous payment procedure
- Withholding/cutting amounts from payments without contractual basis

<u>Owner's Obligations – Others</u>: The owner's obligations are not only limited to payment. Other important obligations include things such granting access to site on time, making fair valuations to change orders, replying to requests and queries within reasonable time, providing timely inspections and tests, and providing subsurface information. The owner's failure to abide by his obligations result in disputes.

Ramachandra and Rotimi (2014) suggest that although owner's provisions are set out in the contract, related disputes still persist due to non-compliance of such provisions. They also suggest that common forms of owner's obligations problems can be intentionally or unintentionally caused by upper-tier construction parties. However, it is claimed that both the unintentional and some of the intentional contractual problems are caused by lack of strong understanding of the provisions.

5.2 Objective

The objective of this chapter is to present contract administration guidelines for utilizing owner's obligations clauses under the most widely used national and international standard forms of design-build contracts.

5.3 Background on Legal Systems

Civil law and the common law are the two laws that are governing most of the nations today. In common law, the judges are to practice the same form of justice that a commoner would (Bockrath and Plotnick, 2011). In order to make sure that the treatment of cases is executed fairly, each case that is solved, each rule that is applied and each outcome that is decided upon, is recorded. These are later used as precedents to determine the outcomes of other cases that have similarity with the recorded ones (Eladaway and Kandil 2010, Arnold-Baker 2008). The common law is the legal system governing the US and nations which were under the ruling of the British Empire. Due to the long living differences of the English and the Americans, the common law followed in both the countries is not exactly the same. The main variations are related to the judicial procedures and the hierarchy of the courts; however, they are both similar when it comes to relying on precedents. On the other hand, civil law places a few people on a higher ground who can improve the entire population (Bockrath and Plotnick, 2011). The civil law bounds judges to make rulings based on extensive legal codes and regulations rather than precedents (Rovine, 2014).

Generally, it is vital for contractors to be familiar with, and abide by, the legal system of the countries that host their projects. An example of a major difference between legal systems is the penalty clause and the liquidated damages. Civil law in most countries allows that a penalty for a contractor's delay to be added for encouraging contractors to complete projects on time. However, according to common law, a penalty is against the public policy. Therefore, in such cases, any clause for penalty in unenforceable. To encourage contractors to complete projects in time, common law allows for a "liquidated damage" clause. According to this, the amount of damage that is estimated to take place due to the delay is calculated in advance. An example that goes on the same lines as the one above is in the warranties against latent defects. Under the French civil law for example, the contractor is guarantees the integrity of the structure for ten years or more. Even if an agreement states a lesser warranty period, this agreement will become void and the ten-year rule will apply. In contrast, the common law, will consider the period stated in the agreement. An extensive analysis has of the construction clauses influenced by both the systems has been made by Klee (2014).

5.4 Background on the Design-Build Delivery System

The most commonly used delivery methods for construction projects are design-bid-build (DBB) and design-build (DB). DBB is the traditional delivery system where an owner contracts separately with a designer and a contractor. As such, the contractor starts the construction works only when the design documents are ready. On the other hand, in the DB delivery system, the owner contracts with a single entity to perform both the design and construction under a single design-build contract. This type of contract enables a single point of responsibility for both design and construction (Moore 1998).

A comparative study that was published by the Construction Industry Institute (CII) and sponsored by the National Institute for Standards and Technology (NIST) found that DB projects were about four times larger than DBB projects in terms of project cost (Thomas et al 2002). That study, as well as other recently published studies, suggest that DB projects generally outperform DBB projects in changes, rework, and practice use (Thomas et al 2002; Riley et al. 2005; Hale et al. 2009; Rosner et al., 2009).

Due to its many advantages in allocating clear responsibilities and incorporating project complexities, the use of the DB method has increased noticeably in the last decade; especially in large and complex projects (Shrestha et al 2011). In fact, the market share for the DB method increased from 29% in 2005 to 39% in 2013; while the market share for the DBB method decreased from 67% in 2005 to 52% in 2013 (Dugan and Patel 2013). For large projects, it was estimated that more than half of projects above $10 million are being completed through the DB method (Dugan and Patel 2013). For example, between 1990 and 2002 alone, approximately 140 SEP-14 projects, worth $5.5 billion, were completed using the DB delivery method (FHWA 2006).

5.5 Methodology

The owner's obligations can be categorized into two main categories: 1) owner's payment obligations, and 2) owner's "other" obligations. Such categorization is made because payment is the major obligation of the owner, while all of the other obligations are relevantly minor. The word major and minor are used in the context of the amount of disputes. As such, this chapter is divided into 2 subchapters (Section 5.7 and 5.8) as shown in Figure 5.1. Section 5.7 covers owner's payment and Section 5.8 covers the owner's "other" obligations.

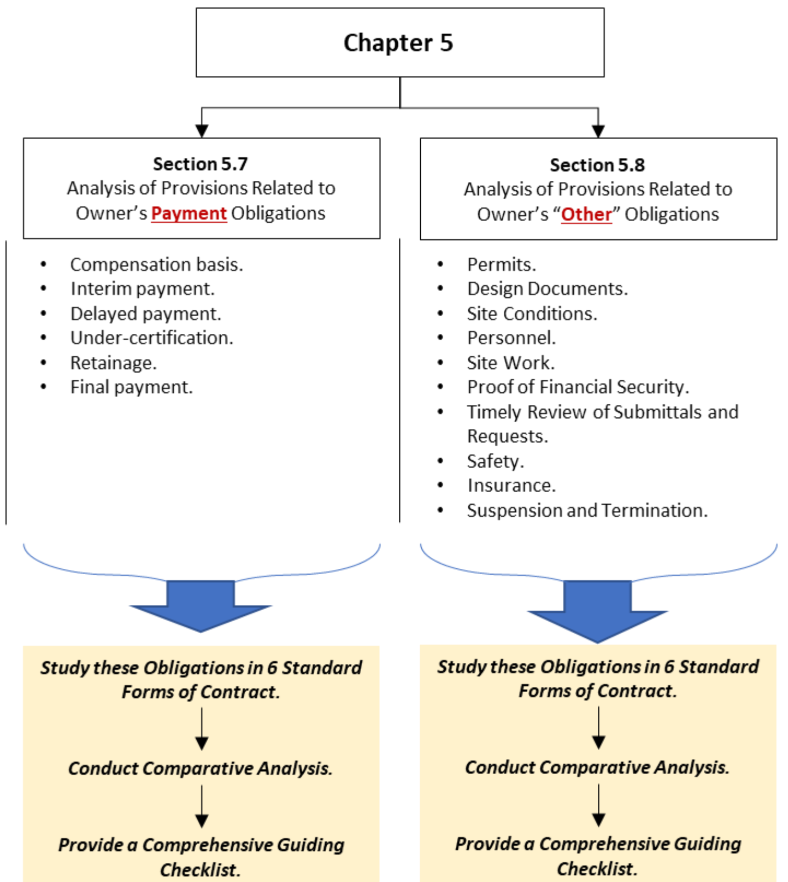


Figure 5.1. Division of the Analysis Work of Chapter 5

The following methodological steps will be followed in each of sections 5.7 and 5.8:

1. Analyze the provisions related to the owner's payment obligations (for section 5.7) and

other obligations (for section 5.8) under the most common national and international forms of design-build contract.

2. Highlight the differences and commonalities among the analyzed contracts in a summarized form.
3. Provide an extensive checklist to act as a:
    a. tool for assessing and enhancing the understanding of the parties to a project's existing contractual clauses related to owner's obligations, and as a
    b. guideline for drafting contractual clauses related to owner's obligations in new contracts.

5.6 The Analyzed Standard Forms of Contract

The mostly used national and international forms of contract for DB projects have been identified. The forms of contract that will be analyzed are:

1. **American Institute of Architects (AIA):** The AIA was found in 1857 with the main objective of promoting the scientific and practical perfection of the members associated with it and to increase the professional standing (AIA 2016). The AIA Documents Committee, which is responsible for drafting the AIA's contract documents, consists of owners, contractors, attorneys, architects, and engineers. The committee drafts and update suites of contract documents on a uniform ten-year basis. Currently, there is nearly 200 forms and contracts by the AIA. The studied standard form of agreement is form *A141-2014: Standard Form of Agreement between Owner and Design-Builder*.

2. **ConsensusDOCS:** The forms under AIA received some criticism by the professionals as it was believed that they sided with architects and owners against the design-builders. This triggered the publication of ConsensusDOCS in September 2007 (Harris and Perlberg 2009). ConsensusDOCS contracts are developed by an alliance of 41 industry associations representing owners, contractors, subcontractors, designers and sureties. ConsensusDOCS contracts protect the best interests of the project rather than a singular party, yielding better project results and fewer disputes (Harris and Perlberg

2009). The studied contract is the *ConsensusDOCS 410: Standard Design-Build Agreement and General Conditions between Owner and Design-Builder*.

3. **The Engineers Joint Contract Documents Committee (EJCDC):** The EJCDC is a joint venture of four major organizations of professional engineers and contractors, namely the American Council of Engineering Companies (ACEC), the National Society of Professional Engineers (NSPE), and the American Society of Civil Engineers (ASCE). The studied contract is the *EJCDC D-700: Standard General Conditions of the Contract between Owner and Design/Builder*.

4. **International Federation of Consulting Engineers (FIDIC):** The FIDIC is an international standards organization for the construction industry. The acronym FIDIC comes from the French name "Fédération Internationale Des Ingénieurs-Conseils". Its forms of contract are used in international projects, especially by the World Bank. The studied contract is the *FIDIC Yellow Book: Conditions of Contract for Plant and Design-Build*.

5. **Joint Contracts Tribunal (JCT):** The JCT was founded by the National Federation of Building Trades Employers (NFBTE) and the Royal Institute of British Architects (RIBA) in England in 1931. Since then, it has produced several standard forms of contract and guidance notes for the construction industry. The studied contract in this research is the *JCT DB 2011*.

6. **The New Engineering Contract (NEC):** The institute of Civil Engineers established a suit of standard types of construction contracts naming New Engineering Contract (NEC). In 1993, the first NEC contract, known as the "New Engineering Contract", was established. It was written using simple language and it helps to prompt good management rather than frustrating it (NEC 2016). The ultimate version of NEC suite was inaugurated in 2005 after several alterations. That suite has 39 contract documents. The studied contract in this research is the *NEC3 Engineering and Construction Contract*.

5.7 Analysis of Provisions Related to Owner's Payment Obligations

5.7.1 Payment Conditions Under the AIA A141-2014 Contract

5.7.1.1 Contract Sum

The contract sum is addressed in Article 2 and Article 9 of the contract, namely "Compensation and Progress Payments" and "Payment Applications and Project Completion". The primary compensation basis in this contract is cost-plus. In such arrangement, the owner is subject to pay all the expenses that have been incurred by the design-builder in addition to administrative fees, which can either be a fixed amount or a percentage of the expenses. The expenses also include those of the design-builder's sub-contractors. A subcontractor is defined in this research as firms or people hired by the design-builder to perform services directly related to the project. This includes architects, consultants, suppliers, specialty contractors, etc. The administrative fee, once decided upon, is to be written in the "blank space" in Article 2.1.3.2. To cater to the different types of projects, the contract allows for adjustment of other amounts. The contract also caters to the hourly payments that the design-builder and the sub-contractors charge for the services, if this is agreed upon between the parties. Similarly, it includes clauses for situations where the parties come to an agreement on lump sum amounts or unit prices. In addition to this, the contract also allows for incentives and guaranteed maximum prices.

5.7.1.2 Progress Payments

The contract specifies that interim payments should take be made by the owner every month. An interest is accrued on the owner's payment in case he does not make the payment within a specific number of days after the design-builder submits his invoice as stated in Article 2.1.4.1. The percentage of this interest is to be agreed upon by the parties. The AIA A141, unlike some other forms, allows the parties to set the number of days before the interest rate is applicable. If the interest rate was undecided upon initially, it is considered to be the legal rate of interest that has been prevalent from time to time at the design-builder's primary place of business.

The procedure for the progress payments under the AIA A141 listed in the following bullet points and demonstrated visually in Figure 5.2:

- The design-builder is entitled to submit an itemized "application for payment" to the owner within a minimum of ten days prior to the payment date of the month. This application must be accompanied with certain documentation that is agreed upon between the parties such as data that support the progress of work and the costs that are incurred by the design-builder till the time of submitting the application. Also, if required, the application could be notarized.

- Once the application for payment has been received, the owner is obliged to issue a payment certificate within seven days. The payment certificate states the amount the owner deems as properly due to the design-builder. Also, the owner shall inform the design-builder of the reasons for withholding any sums from his application of payment.

- The owner must deliver the payment by the date agreed upon.

- The design-builder is obliged to pay the sub-contractors within 7 days of receiving the owner's payment.

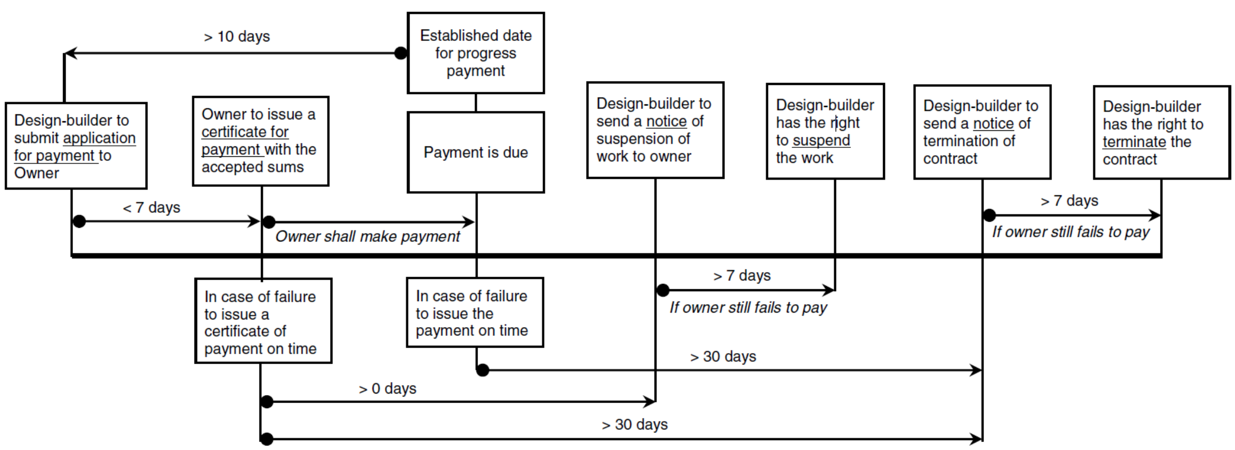


Figure 5.2. Progress Payments under the AIA A141

The design-builder is at liberty to stop the work after 7 days if the owner fails to issue the certificate for payment on time. He can then continue work after the payment is received. Other forms of contract state that the design-builder must give the owner a timely warning before suspending work in this case. However, the AIA A141 gives the design-builder the right to suspend the work directly without warning. In the case of suspension of work due to the owner's failure to make the payment on time or to issue the certificate for payment on time, the design-builder is entitled an extension in deadline, additional costs for delay and stoppage with an interest under article 9.7.

But the contract also gives the owner the leverage to hold the certificate for payment for a reasonable extent to guard against losses and damages by the design-builder, which include defective design, defective construction work, damage to the owner or a separate contractor, and even reasonable evidence that the work cannot be completed for the unpaid balance of the contract sum. However, this "reasonable extent" is not defined in the contract. In the case of the certificate getting withheld, the design-builder needs to be informed of the reasons for that. If a revised payment amount cannot be agreed upon between the owner and the design-builder, the owner has to issue a certificate with the amount he deems due. The time period for this is not specified. The contract just states that this certificate has to be issued "promptly".

Unique properties of AIA A141 regarding interim payment include: (1) the owner can issue joint checks to design-builder and his sub-contractors in case he withheld sums from the design-builder; (2) the owner has the right to furnish information related to completion status and payment data to the sub-contractors; (3) the owner can demand for evidence of the design-builder's payment to sub-contractors. In this case, if the design-builder does not provide such evidence within 7 days, the owner has the right to contact the sub-contractors himself to obtain such data to ensure the sub-contractors are paid. There is no obligation on the owner to make payments to them though.

5.7.1.3 Final Payment

The design-builder shall submit the final application for payment after completing the contracted works. Promptly after receiving this application for payment, the owner shall make inspections of the work and issue a final certificate of payment to the design-builder. The contract does not define what "promptly" exactly means. This gives the impression that the AIA contract is biased towards the owner's benefit since there is no hard time limitation for when he should issue the final certificate of payment (Harris and Perlberg 2009). Certain deliverables, detailed in Article 9.10.2, must be submitted by the design-builder with the final application before his payment becomes due. According to the contract, by receiving the final payment, the design-builder waives any claims issued by him, except those which were unsettled at the time of the final application.

5.7.2 Payment Conditions Under the ConsensusDOCS 410 Contract

5.7.2.1 Contract Sum

Under the ConsensusDOCS 410, the compensation basis is also cost-plus. The total contract sum is named the Guaranteed Maximum Price (GMP) in the contract; where it is the addition of the "estimated cost of work" and "design-builder's fees". These are stated in Articles 8 and 7, respectively, of the contract. The cost of work is any cost that the design-builder paid that is directly related to the project such as costs of material, permits, sub-contractors, equipment, etc. The design-builder's fees are those corresponding to profit and indirect cost. This could be a percentage of the cost of work or a fixed fee, as the parties agree. The owner is guaranteed not to pay more than the GMP even if the design-builder incurred costs that exceeds the GMP. This encourages design-builders to finish the project with lower costs. However, amendments could be made to modify the GMP. Conditions for those amendments are listed in several places in the contract.

5.7.2.2 Progress Payments

The contract specifies the progress payments to be made monthly. The corresponding procedures are listed in the following bullet points and demonstrated in Figure 5.3:

- Every month, in the day specified in the contract, the design-builder submits the application for payment to the owner. The contract gives the parties the freedom to set the day of the month at which this submission takes place. The parties can agree to include other documentation with the application for payment such as proofs of material purchase and on-site storage. Article 10.1.8 provides more details regarding this matter.

- No later than 7 days from receiving the application for payment, the owner must notify the design-builder of his assessment (either acceptance, partial rejection, or full rejection). In case of partial or full rejection, the owner must send the design-builder the reasons leading to this rejection.

- The owner must make the payment no later than 15 days from notifying the design-builder of the accepted sums of the application for payment.

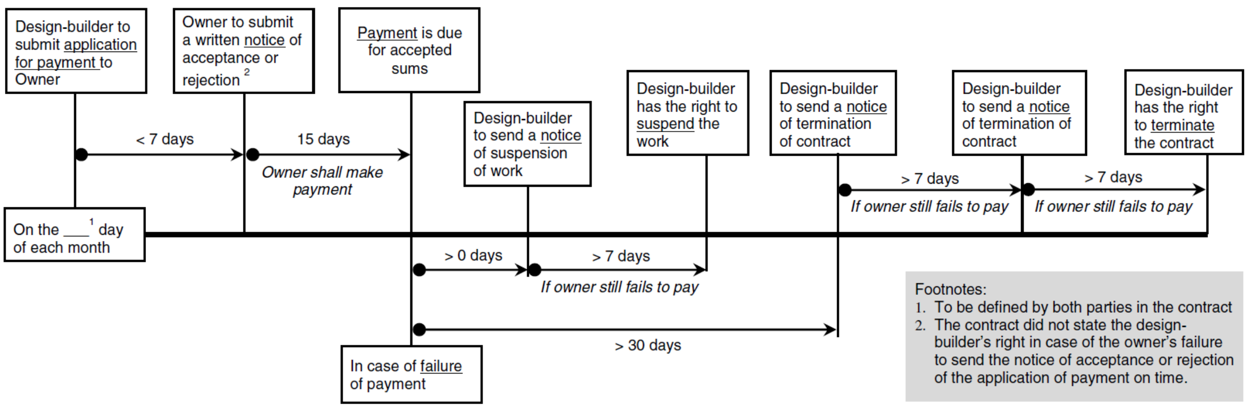


Figure 5.3. Progress Payments under the ConsensusDOCS 410

If both parties do not reach a settlement on a revised amount in the application for payment, the owner shall make payment of the sums that he deems accepted within 15 days of issuing his initial rejection to the design-builder. In this case, the rejected sums would be payable when the reasons for their rejection no longer exist. There is an ambiguity regarding the notice of acceptance/rejection of the sums in the application of payment. The ConsensusDOCS 410 did not specify what happens if the owner does not abide by the 7-day period for issuing such acceptance/rejection notice.

At any time after the owner fails to make the payment to the design-builder on time, the design-builder has the right to inform the owner that he will suspend the work. If the owner still fails to make the payment, the design-builder has the right to suspend the work after 7 days of sending his notice of suspension. The design-builder may resume after he receives the payment. If the period of failure to pay extended to 30 days from the agreed date, the design-builder has the right to inform the owner of his intent to terminate the contract. If the owner still fails to make the payment after 7 days of this notification, the design-builder has the right to terminate the contract immediately.

The ConsensusDOCS is different than other forms of contract when it comes to retention money. Article 10.2 states the how retainage is regulated. The following bullets are taken from the contract to describe the retainage regulations:

- "T*he owner shall withhold no retainage from progress payments after the work is 50% or more complete.*
- *The owner may reduce the amount to be retained at any time.*
- *The owner may release retainage on a portion of the work a subcontractor has completed, in whole or in part, for which this portion has been accepted by the owner.*
- *In lieu of retainage, the design-Builder may furnish a retention bond, acceptable to the owner, to be held by the owner.*" (ConsensusDOCS 410).

Much like the AIA, the ConsensusDOCS – in Article 10.3 - gives the owner the right to regulate or nullify a formerly accepted application for payment to protect himself from any damages caused by the design-builder.

5.7.2.3 Final Payment

When the work is completed, and before issuing the final payment, the owner has the right to request evidence that the design-builder has made all payments relating to material, payrolls, and other work-related expenses. The general conditions did not stipulate the timing at which the final payment is made; which could be worrying to design-builders. Similar to the AIA, the ConsensusDOCS states that by accepting the final payment, the design-builder waives all claims issued by him except all that were not settled at the time of the final payment.

5.7.3 Payment Conditions Under the EJCDC D-700 Contract

5.7.3.1 <u>Contract Sum</u>

The contract allows for either cost plus or unit price as the compensation basis. If the former is used, the contract cost includes the cost of work that is incurred to the design-builder (examples listed in Article 10.01) in addition to the design-builder's fee covering the profit and the overhear; which can be a percentage from the cost of work or a flat fee. If the parties use the unit price as basis for compensation, the unit prices would include all costs incurred to the design builder in addition to his overheads and profits. In this case, the contract sum would be the simple multiplication of the unit prices and the quantities. The EJCDC D-700 does not employ the Guaranteed Maximum Price.

5.7.3.2 <u>Progress Payments</u>

The contract specifies the progress payments to be made not more often than once per month. The corresponding procedures are listed in the following bullet points and demonstrated in Figure 5.4:

- An application for payment is submitted to the owner from the design-builder at the day of the month that both parties agree upon in the contract. The contract states that other supporting document shall be submitted with the application, but it doesn't define what these documents are. As such, parties must define these documents in the special conditions.
- Once the application has been received, the owner must reply to the design-builder to inform him that he has accepted the application or to return the application due to its rejection (while stating the reasons for rejection). This should be done within 10 days.
- The payment must be made by the owner within 10 days of accepting the application for payment.
- If the owner rejects part of the application for payment, he should
- If the payment has not been fully rejected, the owner should pay the amount which is accepted promptly after notifying the design-builder of his partial rejection. The word

"promptly" is risky to the design-builder since the contract does not define what it means in terms of the number of days.

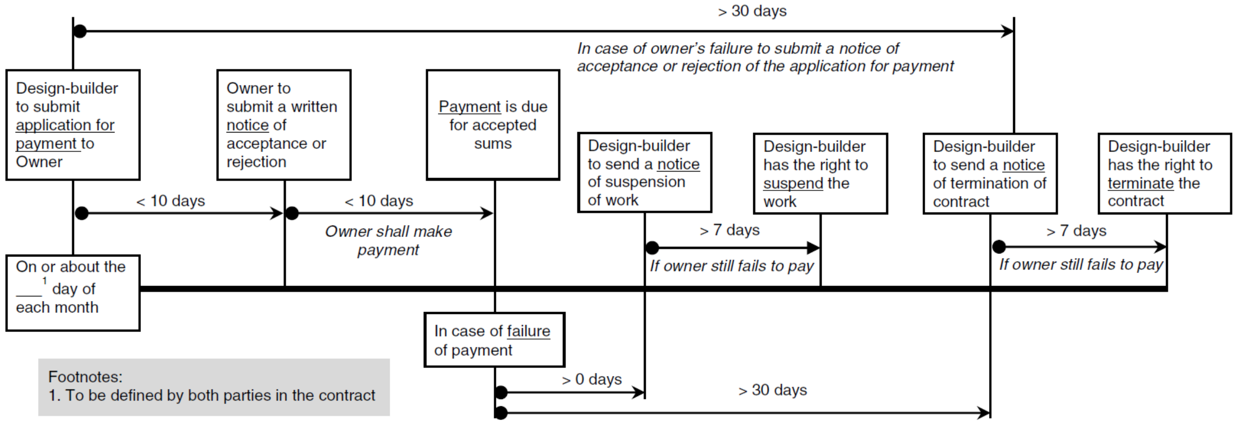


Figure 5.4. Progress Payments under the EJCDC D-700

In the case where the owner is unable to make the payment in the given time, the design-builder has the right to inform the owner that he intends to suspend the work. If the owner is still does not make the payment after 7 days of receiving such notice, the design-builder has the right to suspend the work. Moreover, such delayed sums shall bear interest. The percentage of this interest is decided upon by the parties in the contract.

If the owner does not take any action regarding the design-builder's application for payment within 30 days of receiving it, or if the owner does not make the payment within 30 days of its due time, the design-builder may inform the owner of his intention to terminate the agreement. If the owner still fails to take any remedying action within 7 days of receiving such notice, the design-builder may terminate the agreement. Also, interest will be accrued to the delayed payments.

As for the amount retained from each progress payment, the parties set such amount in the particular conditions of the contract. The owner has the right to make changes to the retained amount in previously approved application for payments to protect himself from any damages caused by the design-builder.

5.7.3.3 Final Payment

The design-builder is entitled to issue the application for final payment following procedures similar to those of the progress payments once the work is complete to the owner's satisfaction and to the specifications listed in the contract document. Article 5.04.B.7 and 13.08.A.2 provide details on some documentation that is required to be submitted with the final application for installment. The proof of insurance, maintenance and operation manuals, and inspection certificates are examples of such supporting documents. The acceptance or rejection of application shall be indicated by the owner inside 10 days of receiving the final application payment. The owner should also mention the reasons of rejection while returning the application to the design-builder. In this case, the design-builder shall make the amendments to the application and resubmit it to the owner. Lastly, after acceptance of application, payment should be made within 30 days.

5.7.4 Payment Conditions Under the FIDIC Yellow Book

5.7.4.1 Contract Sum

This contract sets the compasses basis as lump sum; which is not like the previously discussed contracts. This lump sum covers all expenses by the design-builder as well as his overheads and profits. In this arrangement, changes in quantities or prices of material do not change the contract sum; which is risky for the contractor. However, there are situations where this sum could be changed such as in cases of variations and delays that are not caused by the design-builder. Also, the contract allows for basing some of the works on unit price basis. But the majority of the contract is still in lump sum basis. The contract sum is distributed on the different work packages, and sometimes even on the activities, of the project. Setting the sums that are payable in each monthly interim payment is determined by the percentage of progress of the work packages in each month. This percentage of progress is usually based on quantities.

Unlike other forms of contract, the FIDIC yellow book provides detailed provisions regarding the advance payment. The owner shall make the advance payment no later than 21 days after he receives the performance security from the design-builder, or no later than 42 days after he issues the letter of acceptance to the design-builder, whichever comes later. In case, the design-builder is not able to issue the performance security, the owner has the right to withhold the advance payment. Repayment of the advance payment shall be made through deduction of a percentage from each progress payment until the advance payment is fully repaid. include percentage deduction in instalment certificates. The deductions should be made only in progress payments where the total certified sums exceed 10% of the contract value.

5.7.4.2 Progress Payments

In order to determine the amount of progress payment, the parties must refer to the schedule of payments that is included in the contract, due to the lump sum nature of the contract. The instalments in which the contract sum is paid is specified by such schedules. The engineer has the privilege to decide on revisited payments if, at any progress payment, the actual progress that is reported by engineer is different than what is set in the schedule of instalment. The parties have the choice of not setting a schedule of instalments. In this case, the interim payments depend on the actual progress of the design-builder as deemed reasonable by the engineer. Regardless of what the parties decide for payment calculation, the procedure for making such payment are listed in the bullet points below and demonstrated in Figure 5.5:

- After the end of the period for payment that is written in the agreement, the design-builder submits the application for interim payment accompanied with supporting documents that provide evidence of the made progress (such as the progress report). If the period for payment is not stated in the contract, then this application for interim payment is made at the end of each month.
- No later than 28 days after the owner received the application for interim payment, the engineer shall submit an interim payment certificate to the owner stating the sums that he views as fairly deserved by the design-builder, accompanied with documentation supporting such sums.
- No later than 56 days after the engineer receives the application for payment from the design-builder, the owner shall pay the sums stated in the engineer's interim payment certificate.

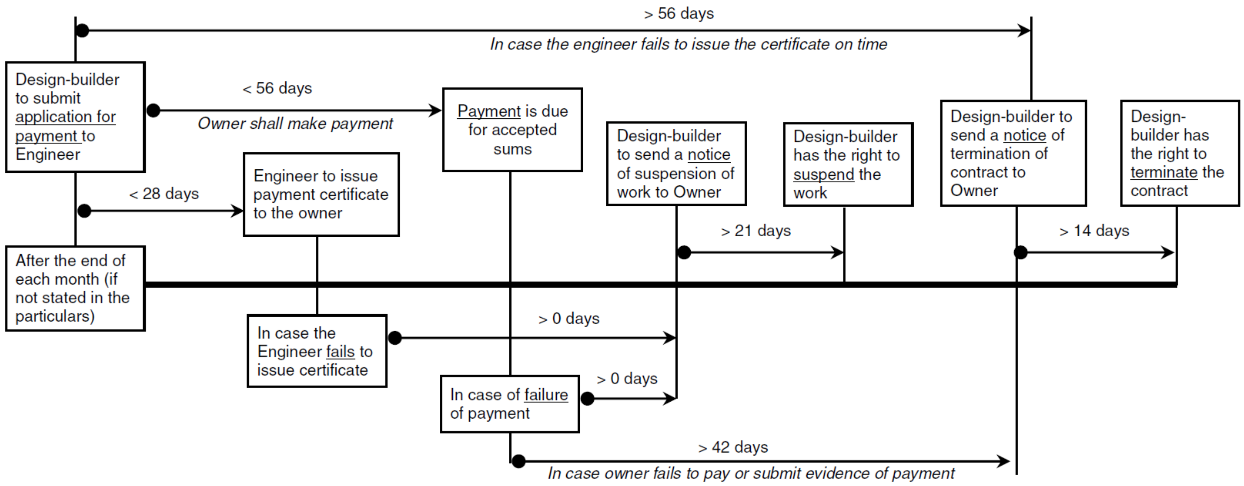


Figure 5.5. Progress Payments under the FIDIC Yellow Book

Design-builders must be keen to submit the performance security, because Article 14.6 states that no sums are considered payable to the design-builder if he fails to submit the performance security and the owner approves it. If the executed work is not done in accordance to the contract, the engineer can withhold the interim certificate. Moreover, proper amendments can be made by engineer to former payment certificates so protect the owner from damages caused by the design-builder. The design-builder is entitled to interest to be accrued on delayed payments. Such interest is compounded monthly. Since the FIDIC is an international contract, it states that such interest is set as "three percentage points above the discount rate of the central bank in the country of the currency of payment, and shall be paid in such currency" [FIDIC Yellow Book].

The design-builder has the right to suspend the work or make reduction in the rate of work if the engineer does not issue the payment certificate within the timeline mentioned in contract or if the owner does not make the payment within the timeline. The process for such suspension is as follows: (1) any day after the owner fails to make the payment or the engineer fails to issue the certificate on time, the design-builder notifies the owner his intention to suspend the work, then (2) the design-builder may suspend the work after 21 days of sending this notice if the owner and engineer do not take remedying actions.

Finally, the performance security "shall be returned to the design-builder" immediately after this notice and design-builder shall be given pay by employer for the completed tasks in addition to any loss or loss of profit as a result of termination of work. When talking about covering various situation “regarding payment and non-payment, FIDIC” is very comprehensive.

According to the contract, Clause 16.2 states that the design-builder has the right to terminate the agreement if: “ (a) he does not receive the reasonable evidence within 42 days after giving his notice of suspensions, (b) the engineer fails, within 5 days after receiving the interim payment application and its supporting documents, to issue the relevant payment certificate, or (c) the design-builder does not receive the amount due within 42 days after the date of the payment has passed.”

One notice here is that the FIDIC is more comprehensive than the other discussed forms of contract as it covers all possible scenarios and it does not allow for any intended or unintended ambiguity.

5.7.4.3 Final Payment

After completing the works, the engineer issues a performance certificate that certifies the design-builder’s completion of work in accordance to the contract documents. Within 56 days of the data of issuing such certificate, the design-builder submits a final statement for payment to the engineer, accompanied with supporting documentation. The engineer has the right to request modifications to be made of that statement. The final payment certificate shall be issued to the employer by the engineer within 28 days of the day the design-builder submits the final statement to the engineer. Within 56 days of receiving the final payment certificate, the owner shall make payment of the certified sums in such certificate to the design-builder.

As for paying the retention money at the end of the project, the contract states the following in Article 14.9: “When the taking-over certificate has been issued for the works, and the works have passed all specified tests, the first half of the retention money shall be certified by the engineer for payment … Promptly after the latest of the expiry dates of the defects notification periods, the outstanding balance of the retention money shall be certified by the engineer for payment”.

5.7.5 Payment Conditions Under the JCT DB 2011 Contract

5.7.5.1 *Contract Sum*

In JCT provisions, the basis for setting the contract sum lack some clarity. The basis for compensation can be very easily misinterpreted by the unpracticed contract administrators. This lack of clarity is also present when it comes to the valuation methods used in the interim payments. Although it is not plainly mentioned in the JCT provisions, the compensation is based on lump sum. The parties set the amount of the advance payment and the corresponding dates it in the particular conditions.

The design-bid-build contract of the JCT is similar to the mentioned contracts in its need for an independent party to certify the works. However, in this design-build JCT contract, there is no third party that makes such certification. The design-builder and the owner are the ones that are involved in evaluating the work. There are two alternatives when it comes to the time of evaluation. In alternative A, the design-builder submits his application for payment after the completion of stages that are set in the contract rather than in regular basis. In alternative B, the design-builder submits such application at regular intervals, such as monthly, as set in the contract. The meaning of "due date" also differs based on which alternative the parties are using. In alternative A, due dates are the dates at which the design-builder agree to complete the work at the different stages. Such stages and their due dates are to be set by the parties in the contract particulars. In alternative B, the due dates are the days of the month set in the particulars.

If the parties do not specify the percentage of retention money, the JCT sets it to three percent of the contract sum. Such percentage is not easy to locate in the contract. The provisions related to payment in the JCT are not easy to understand and follow. According to Abotaleb and El-adaway (2016), "*since the issuance of the JCT DB 2011 there have been several cases relating to the payment provisions under JCT contracts, perhaps suggesting that the JCT need to consider improving the clarity of the payment conditions (DLA Piper 2015).*"

5.7.5.2 Progress Payment

The contract specifies the progress payments to be made not more often than once per month. The corresponding procedures are listed in the following bullet points and demonstrated in Figure 5.6:

- In the dates that are set in the particular conditions, the design-builder send an application for payment.
- The owner shall submit payment notice to the design-builder within 5 days of the due date that is set in the contract. This payment notice should inform the design-builder of the sum that the owner intends to pay. It also should contain information on how the owner calculated this sum. If the approved sum is less than the sum submitted by the design-builder in the application for payment, then this payment notice would have the name of "pay less notice".
- No later than 14 days from the due date, the owner shall make the payment to the design-builder.

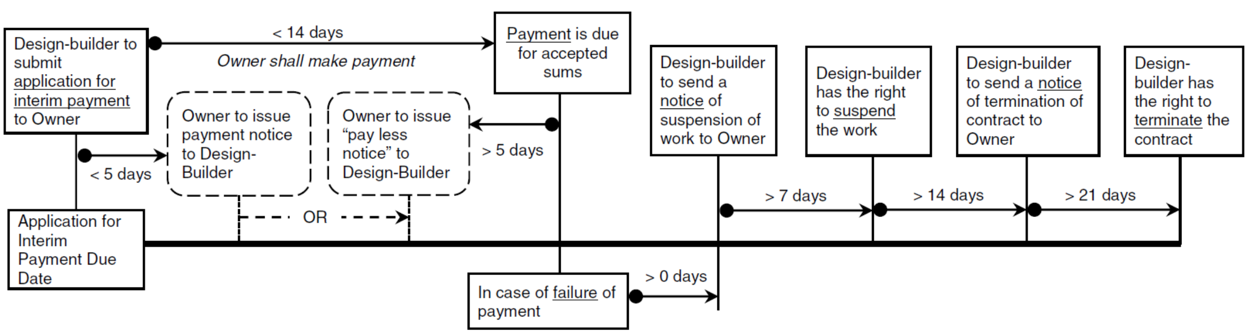


Figure 5.6. Progress Payments under the FCT DB 2011

Interest is accrued on any delayed payments. However, the contract does not specify how this interest is calculated. As such, parties must set this in the particulars. The design-builder has the right to suspend the work in cases of delayed payment, and even terminate the contract if this delay became longer. Figure 5.6 provides visual representation of the process of suspension and termination by the design-builder in cases of delayed payment.

5.7.5.3 Final Payment

The provisions discussing final payment in the JCT are well-rounded and do not have ambiguities. However, they are not easily understood by inexperience contract administrators. Within 3 months after practical completion of the work, the design-builder shall submit the final statement for payment. If the 3 months pass without issuing such statement, the owner may notify the design-builder to issue it. If still the design-builder fails to issue the statement for final payment for two months after the owner's notice, the owner has the right to issue the statement himself. The contract gives the parties the right to dispute each other's statements within one month from the other party issuing the statement. The owner shall make the final payment within 28 days from the due date. In this case, the due is defined by Article 4.12.5 of the JCT DB 2011 as: "*the date one month after whichever of the following occurs last: (1) the end of the Rectification Period in respect of the Works or the last such period to expire; (2) the date stated in the Notice for Completion of Making Good under or in the last such notice to be issued; or (3) the date of submission to the other Party of the Final Statement or, if issued first, the Employer's Final Statement*."

5.7.6 Payment Conditions Under the NEC3 Engineering and Construction Contract

5.7.6.1 Contract Sum

On compensation basis, the NEC3 agreement provides 6 different options for parties to choose from. The parties must write the type of option they are using in contract. The options are as follows:

- Option A: priced contract with activity schedule → for lump sum
- Option B: priced contract with bill of quantities → for unit price
- Option C: Target contract with activity schedule → for lump sum
- Option D: Target contract with bill of quantities → for unit price
- Option E: Cost reimbursable contract → for cost-plus

Eggleston (2015) provides a good comparison between the above-mentioned options for reimbursement. The contract also has the flexibility to incorporate incentives clauses to encourage the design-builder to complete the work quickly. Under this contract, a project manager is required to be hired in the project. His role is similar to the role of the the engineer in the FIDIC agreement and the architect in the AIA agreement.

5.7.6.2 Progress Payments

If an advance payment is agreed upon between the parties, the contract specifies that such payment should be made no later than 4 weeks from the contract date or the data the owner receives the advance payment bond, whichever is later. Also, such bond is not obligatory. The parties should agree on whether it is needed or not.

Monthly assessment dates should be agreed upon between the parties. Unlike in other forms of contract, in the NEC3, the design-builder does not have to submit application for payments at the monthly assessment dates. Instead, the project manager is responsible for assessing the contractor’s work and evaluating the sum due in the agreed assessment dates. After the project manager affirms the approved sum within one week of evaluation date, the owner should pay such approved sum within 21 days of the assessment date. Delayed payments shall accrue interest that is agreed upon by the parties in the contract. Figure 5.7 demonstrates the process of progress payment. It should be noted that, under the NEC3, the design-builder does not have the right to suspend the work in cases of delayed payment. This is unlike the rest of the discussed contracts. Relevant to payment, the design-builder only has the right to terminate the agreement if the owner does not pay the sums certified by the project managers for 13 weeks starting the date of the project manager issuing the certificate.

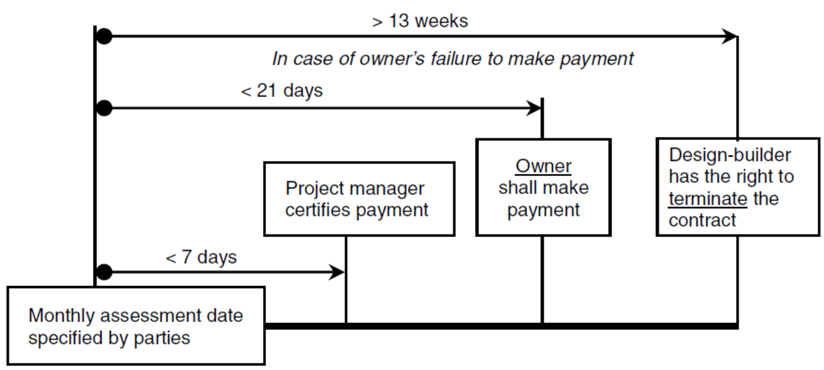


Figure 5.7. Progress Payments under the NEC3

5.7.6.3 Final Payment

The steps for making the final payment and the progress payment are similar in the NEC3 contract. The project manager makes the final evaluation after which owner makes the instalments within 21 days of the assessment date. In case of retention, the NEC3 allows the parties to decide on the amount of retention and gives them the freedom to set the relevant arrangements. The retained sums are paid to the design-builder on two equal instalments. The first instalment is due when the design-builder completes executing the whole of the works. The second instalment is due when the defects certificate is issued.

5.7.7 Summarized Comparative Analysis of Payment Conditions

Table 5.1 summarizes the key elements of the provisions related to owner's payment obligations in the analyzed contracts. This enables easy comparison between the different contracts with regards to the points of analysis. Parties should find the comparison in Table 5.1 of great value as it helps in easily determining the risks associated with the different standard forms of contract that used in their projects. If no standard form of contract is yet set for the project, Table 5.1 could aid the parties in deciding on which standard form of contract to use to suit their needs and risk tendencies.

5.7.8 Guidelines for Drafting Payment Clauses

In case the parties are administering the project's contract or in the process of drafting a new contract, they must have the same understanding of the clauses to avoid any disputes arising from poor administration. For this purpose, a checklist the has 65 questions was developed based on the conducted comprehensive analysis of the owner's payment obligations. The contract administrator should be able to answer all questions in the checklist to ensure that the contract is free of ambiguities and to ensure that he/she has proper understanding of the contract provisions. In case a new contract is still being drafted, the checklist will aid such drafting process. The new contract should contain provisions that clearly answer those 65 questions. The developed checklist (Table 5.2) is only concerned with the owner's payment obligations. It should be noted that they assume that there are direct communications between the owner and the design-builder without having an architect or an engineer in between.

Table 5.1. Comparison between Standard Forms of Contract (Owner's Payment Obligations)

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
Compensation basis	Cost plus.	Cost plus.	Cost plus or unit price.	Lump sum.	Lump sum (if based on stage payments) or unit price (if based on periodic payments).	Lump sum, unit price, or cost plus; depending on the parties' selection.
GMP or incentives program?	It has mechanisms for GMP and incentives.	Guaranteed Maximum Price.	Not stated.	Not stated.	Not stated.	It has mechanisms for GMP and incentives.
Advance payment?	Not stated in the general conditions.	Not stated in the general conditions.	Not stated in the general conditions.	Amount and repayment installments of the advance payment are to be set in the particular conditions.	Amount and repayment installments of the advance payment are to be set in the particular conditions.	Amount and repayment installments of the advance payment are to be set in the particular conditions
When does the owner pay the advance payment?	Not stated in the general conditions.	Not stated in the general conditions.	Not stated in the general conditions.	Within 42 days after issuing the letter of acceptance or within 21 days after receiving performance security; whichever is later.	Agreed by the parties in the particular conditions.	Within 4 weeks of the later of the contract date or the date of receiving the advance payment bond.
Any special conditions related to the advance payment other than traditional deductions from periodic payments till full recovery?	No.	No.	No.	Advance payment deductions take place only in the payment certificates where the certified cumulative sums exceed 10% of the contract sum. Also, the deductions shall be made at the amortization rate of 25% of the amount of each payment certificate until the advance payment has been repaid in full.	No.	No.
What is the length of the payment cycle?	One month.	One month.	Not more often than once a month.	One month.	The parties can agree to make it by stage or by period (monthly up to the practical completion then bi-monthly after that).	One month.
When does the design-builder issue application of payment?	At least ten days before the date established for each progress payment, which is specified by the parties in the particular conditions.	Specified by the parties in the general conditions.	Specified by the parties in the particular conditions.	Design-builder issues the application to the Engineer after the end of each month, if not stated in the particulars.	Should be specified by the parties in the particular conditions.	The design-builder does not issue an application for payment. The project manager makes the monthly assessment.

Table 5.1. Continued. Comparison between Standard Forms of Contract (Owner's Payment Obligations).

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
What should be submitted with the application of payment?	Any items requested by the owner as evidence for work progress, expenses, and payment of sub-contractors.	The contract did not specify whether supporting documents for finished works and incurred costs are needed or not.	Supporting documents for finished works and incurred costs such as material invoices. The contract did not state details.	Evidence of progress; mainly the monthly progress report.	The contract did not include details about the required evidence.	The design-builder does not issue an application for payment.
When does the owner issue the acceptance or rejection, in full or in part, of the application for payment?	Certificate of payment: No later than 7 days from receiving the application for payment	No later than 7 days from receiving the application for payment.	No later than 10 days from receiving the application for payment.	Within 28 from receiving the application, the Engineer shall issue the certificate to the Owner.	No later than 5 days from receiving the application for payment.	The project manager certifies the payment within one week of each assessment date.
What happens if the owner is delayed in issuing such notice / certificate of payment?	design-builder has the right to stop the work after additional 7 days until payment of the amount owning has been received	Not stated.	<u>Termination:</u> After 30 days of the design-builder's submittal of application for payment, he sends a notice of his intention to terminate the contract. After 7 days of such notice, he has the right to terminate the contract.	The design-builder should wait till he gets the payment on time. Being late in issuing the certificate doesn't affect the payment time.	The design-builder should wait till he gets the payment on time. Being late in issuing the certificate doesn't affect the payment time.	The project manager is the one who certifies the payment within one week of each assessment date. If he is late, the design-builder should continue working until he has the right for termination in case of owner non-payment.
Warranty of title in progress payments	The Design-builder warrants that title to all work, materials and equipment covered by an application for payment will pass to the owner free of all liens upon receipt of such payment by the design-builder.	The Design-builder warrants that title to all work, materials and equipment covered by an application for payment will pass to the owner free of all liens upon receipt of such payment by the design-builder.	The Design-Builder warrants that title to all work, materials and equipment covered by an application for payment will pass to the owner free of all liens upon receipt of such payment by the design-builder.	Not stated.	Not stated.	Whatever title the design-builder has to plant and materials passes to the owner if it has been brought within the working areas.
When does the owner make the actual payment?	In the date established for each progress payment, which is specified by the parties in the particular conditions.	No later than 15 days from receiving the application for payment.	No later than 10 days from issuing the acceptance of the application of payment.	Within 56 days after the Engineer receives the application for payment from the design-builder.	Within 14 days after the due date of the interim payment.	Within 3 weeks of the assessment date.

Table 5.1. Continued. Comparison between Standard Forms of Contract (Owner's Payment Obligations).

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
What happens if the owner is delayed in paying?	Termination: After 30 days of the date the payment is due, the design-builder sends a notice of his intention to terminate the contract. After 7 days of such notice, he has the right to terminate the contract.	Suspension: As soon as the payment is due, the design-builder sends a notice of work suspension. After 7 days of such notice, he has the right to suspend the work until the owner makes payment. Termination: If owner still fails to make payment; then, after 30 days of the date the payment is due, the design-builder sends a notice of his intention to terminate the contract. After 7 days of such notice, he sends another notice stating his intention to terminate. After 7 days of such notice, he has the right to terminate the contract.	Suspension: As soon as the payment is due, the design-builder sends a notice of work suspension. After 7 days of such notice, he has the right to suspend the work until the owner makes payment. Termination: If owner still fails to make payment; then, after 30 days of the date the payment is due, the design-builder sends a notice of his intention to terminate the contract. After 7 days of such notice, he has the right to terminate the contract.	Suspension: The design-builder has the right to suspend the work or reduce the rate of work after giving not less than 21 days' notice to the owner. Termination: If he still does not receive the amount due within 42 days after its expiry date, the contractor has the right to terminate the work after giving a 14 days' notice to the owner.	Suspension: After 7 days of giving notice of suspension, the design-builder has the right to suspend the work until payment is made in full. Termination: If the suspension continued for more than 14 days, the contractor has the right to submit a notice of termination and is entitled to terminate the work after 21 days of such notice	Termination: If the owner did not pay an amount certified by the project manager within 13 weeks of the date of the certificate, the design-builder has the right to terminate the agreement.
Shall unpaid payments that are due bear interest?	Yes, the parties should state it. If not stated, then it is the legal rate prevailing from time to time at the principal place of business of the design-builder	Yes, the interest rate is the prime rate prevailing at the place of the Project.	Yes, the value of interest is agreed upon by the parties in the particular conditions.	Yes, to be calculated at the annual rate of three percentage points above the discount rate of the central bank of the country of the currency of payment.	Yes, but the contract did not state the basis of calculating that interest rate.	Yes, the interest is set by the parties and compounded annually.
If the contractor suspends works due to owner's failure to issue certificate of payment or make payment on time, then the owner remedied by issuing the certificate of payment or making the payment, what are the design-builder's compensation?	Such stoppage grants the design-builder proper extension of time and addition in the contract sum by the amount of the design-builder's reasonable costs of shut-down, delay and start-up.	Such stoppage grants the design-builder proper extension of time and addition in the contract sum (cost plus fee).	Such stoppage grants the design-builder proper extension of time and addition in the contract sum by the amount of the design-builder's reasonable costs of shut-down, delay and start-up.	The design-builder shall be entitled reasonable extension of time and payment of cost and profit corresponding to such suspension.	The design-builder shall be entitled to a reasonable amount in respect of costs and expenses reasonably incurred by him.	Not applicable. The design-builder does not have the right to suspend the work in case of owner non-payment.

Table 5.1. Continued. Comparison between Standard Forms of Contract (Owner's Payment Obligations).

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
Does the owner's progress payment deem his acceptance of any work not conforming to the contract documents?	No	No	No	No (engineer).	No	No.
What happens if the owner rejects the application for payment, in whole or in part?	The owner shall notify the design-builder of the amount that he deems due and owning. However, the contract did not state when to make such notification or when to make these due payments. The owner also has the right to pay the sub-contractors directly in this case.	If the owner and design-builder cannot agree on a revised amount, then within 15 days of the initial rejection in part, the owner shall pay the accepted amounts to the design-builder. Those items rejected by the Owner shall be due and payable when the reasons for the rejection have been removed.	After such rejection, the owner shall promptly pay the design-builder the accepted sums. Those items rejected by the Owner shall be due and payable promptly after the reasons for the rejection have been removed.	The procedures after that are not clear.	The owner shall issue a "pay less" notice to the design-builder stating the amount that he finds suitable. Issuance of this notice should not be later than 5 days after receiving the application. Payment of such amount shall be made within 14 days after the due date of the interim payment.	The project manager is the party in charge of that. He certifies approved sums and the owner should make payment. If amounts are corrected in later certificates, they accrue interest.
In progress payments, does the owner have the right to ask for evidence of the design-builder paying his sub-contractors?	Yes	Yes.	Yes.	Not stated.	Not stated.	Only in the cost plus contract option.
Is the owner obliged to pay the design-builder's subcontractors in case they're not paid by the design-builder?	No.	Not stated.	Not stated.	Not stated.	Not stated.	Not stated.
What is the value of retainage?	Specified by the parties in the particular conditions.	Specified by the parties in the general conditions.	To be specified by the parties in the particular conditions.	Specified by the parties in the particular conditions.	3% of the contract sum.	Specified by the parties in the particular conditions.
Repayment of retention money to the design-builder.	The owner and design-builder shall agree on a mutually acceptable procedure for repayments of retention in the particular condition.	The retainage percentage is withheld from each progress payment only until the work reaches 50% progress.	The retainage percentage is withheld from each progress payment and the total withheld retainage is paid to the design-builder in the final payment.	Half of the retention is returned to the design-builder at the issuance of the taking-over certificate and the other half is returned at the end of the defects liability period.	Half of the amount retained is released on certification of practical completion and the rest is released upon certification of final statement.	Half of the retained money is returned to the design-builder at the completion of the whole of the works and the other half is returned at the issuance of the defects certificate

Table 5.1. Continued. Comparison between Standard Forms of Contract (Owner's Payment Obligations).

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
Can the owner furnish the design-builder's sub-contractors evidence of payment?	Yes, but he is not obliged to do so.	Not stated.	Not stated.	Not stated.	Not stated.	Not stated.
When does the owner issue the certificate for final payment (assuming that all deliverables are granted)	Promptly	The contract does not require a certificate for final payment.	Within 10 days of receiving the final application for payment and its supporting documents.	Within 28 days after receiving the final statement, the engineer shall issue to the employer the final payment certificate.	No later than one month after the date of its issuance by the design-builder.	The project manager certifies the payment within one week of the final assessment date.
When does the owner make the final payment? (in case of acceptance of the application of payment)	Within the time agreed upon by the parties.	When work is completed and the satisfactory evidence of design-builder's costs are furnished.	Within 30 days of receiving the final application for payment and its supporting documents.	Within 56 days after receiving the payment certificate from the Engineer.	No later than 28 days after one month from issuing the undisputed final statement.	Within 3 weeks of the final assessment date.
Can the owner adjust or reject an application for payment or nullify a previously approved application for payment?	Yes, to protect himself from loss resulting from damage cause by the design-builder.	Yes, to protect himself from loss resulting from damage cause by the design-builder.	Yes, to protect himself from loss resulting from damage cause by the design-builder.	(Engineer) Yes, to protect the owner from loss resulting from damage cause by the design-builder.	Yes, to protect himself from loss resulting from damage cause by the design-builder.	Yes, the project manager is the party with this authority.
Does acceptance of the final payment by the design-builder constitute a waiver of claims by the design-builder?	Yes, but not those that are unsettled at the time of final application of payment.	Yes, but not those that are previously made in writing and still unsettled.	Yes, but not those that are previously made in writing and still unsettled.	Yes, but not those that are previously made in writing and still unsettled.	Yes, but not those that are previously made in writing and still unsettled.	Yes, but not those that are previously made in writing and still unsettled.

Table 5.2. Checklist for Drafting Clauses Related to Owner's "Payment" Obligations

Category	Questions Regarding Payment Provisions under Design-Build Projects
Compensation Basis	• Lump sum, cost plus, unit price, mix, other… • Payment cycle length (by-weekly, monthly, bimonthly, stage-by-stage). • Presence of incentives for quick completion. • Presence of guaranteed maximum price (in cases of cost plus or unit price). • If the contract is lump sum, should the contract submit schedule of rates or bulks of prices for items for the valuation? • How are the taxes incorporated in the contract sum? • What happens if the actual quantities are excessively more than the estimated quantities? and how to quantify the word "excessively"?
Advance Payment	• Is there any advance payment? • How much is the advance payment? • When does the owner make the advance payment? • What happens if the owner does not make the advance payment on time? • What happens if the owner makes only a portion of the advance payment on time? • What is the recovery technique for the advance payment? (Ex: percent deductions from the interim payment)
Interim Payment – Application for Payment	• When does the design-builder submit the application for payment? • What happens if the design-builder submits the application for payment earlier or later than what is stated in the contract? • What data should be included in the application for payment? • How are the works valued? (Ex: quantities by unit rates or %completion by bulk price) • Does valuation include materials stored onsite or offsite? • What happens if some of the data is missing from the application for payment? • Does the application for payment need to be notarized?
Interim Payment – Payment Certificate	• What is the maximum duration that the owner has to revise the application for payment and issue the payment certificate? • When does the owner have the right to reject the application for payment, in whole or in part? • What if the owner did not issue the payment certificate on time? • If the owner does not agree to the sums claimed by the design-builder in the latter's application, • What document should he is issue (ex: pay less notification)? • When to issue this document? • Should he include justification for approving sums less that the claimed ones? • What rights does the design-builder have if the owner does not issue this document on time? • Can the design-builder challenge the owner's approved sum in the document? • What is the timeline for challenging the sums in the document? • If no agreement could be reached with regards to the deserved sum, what rights does the design-builder have? • Does the owner have the right to ask for evidence of the design-building paying his sub-contractors? • Can the owner adjust or reject an application for payment or nullify a previously approved application for payment?
Interim Payment – Making the Payment	• When does the owner make the payment? • What happens if the owner does not make the payment on time? • Is the design-builder entitled interest in case of delayed payment of the full amount? • Is the design-builder entitled interest in case of undervaluation (in case he could prove it)? • When does the design-builder start accruing interest in case of his entitlement? • What is the frequency of compounding the interest? (compounded annually, monthly, daily …) • Does the design-builder warrant that title to all work, materials and equipment covered by an application for payment will pass to the owner free of all liens upon receipt of such payment? • Is the owner obliged to pay the design-builder's subcontractors in case they're not paid by the design-builder? • Can the owner furnish the design-builder's sub-contractors evidence of payment?
Retention	• What is the value of retention? • How is the retention money recovered? • Is the owner obliged to keep the retention money in a separate bank account? • If retention money is not recovered on time, does it accrue interest?

Table 5.2. (Continued). Checklist for Drafting Clauses Related to Owner's "Payment" Obligations

Category	Questions Regarding Payment Provisions under Design-Build Projects
Suspension	• Does the design-builder have the right to notify the owner of his intent to suspend the works in case the latter did not submit certificate of payment on time? If yes, then within how many days should the design-builder submit this notice? • Does the design-builder have the right to notify the owner of his intent to suspend the works in case the latter did not make the payment of approved sums on time? If yes, then within how many days should the design-builder submit this notice? • Does the design-builder have the right to notify the owner of his intent to suspend the works in case the latter did not make full payment of approved sums on time? If yes, then within how many days should the design-builder submit this notice? • At what conditions is the design-builder entitled to actually suspend the work after sending his notice of intent to suspend? (Ex: If the owner still did not make the payment, the design-builder has the right to suspend the work after 10 days from sending the notice) • If the contractor suspends works due to owner's failure to issue certificate of payment or make payment on time, then the owner remedied by issuing the certificate of payment or making the payment, what is the design-builder's compensation? • Does it include only direct expenses incurred to him due to the suspension? • Does it include overheads as well? • Does it include profit as well? • Does it include interest as well?
Termination	• At what payment conditions is the design-builder entitled to send a notice of intent to terminate the contract? (Ex: if suspension continued for 10 days without payment by owner) • At what conditions is the design-builder entitled to actually terminate the contract? (Ex: If the owner still did not make the payment, the design-builder has the right to terminate the contract after 10 days from sending the notice)
Final Payment	• What are the procedures and the required deliverables for the owner to issue a certificate of final payment? • When should the owner issue the certificate for final payment? (assuming that all deliverables are granted) • When should the owner make the final payment? (in case of acceptance of the application of payment) • What happens if the owner is delayed in issuing the certificate of final payment or in making the payment? • Does acceptance of the final payment by the design-builder constitute a waiver of claims by the design-builder?

5.8 Analysis of Provisions Related to Owner's "Other" Obligations

5.8.1 "Other" Conditions Related to Owner's Obligations Under the AIA A141-2014 Contract

5.8.1.1 Permits

The owner shall assist the design-builder in preparing the required documentation to obtain approvals of government authorities that have jurisdiction over the project. The owner's role is just assistance, the design-builder is the one responsible for preparing and submitting the documentation to the authorities according to Article 3.1.7.

5.8.1.2 Design Documents

In design-build contracts, most of the design is within the obligations of the design-builder. However, the owner must provide design criteria to guide the design-builder and provide basis for evaluation. In the AIA, the owner's design requirements and milestones are part of the contract documents.

5.8.1.3 Site Conditions

The owner must provide to the design-builder any information related to prior tests or investigations conducted for the project involving mechanical or structural systems, chemicals, hazardous materials, and environmental and subsurface conditions. If the design-builder makes a request, the owner shall provide surveys describing physical characteristics of the site including legal limitations, utility locations, geotechnical conditions, and sub-surface investigation. All of the above-mentioned information shall be furnished on the owner's expense.

The owner has the obligation to investigate the site conditions within a "reasonable time" from receiving a notice from the design-builder that the sub-surface conditions differ materially from those indicated in the design-build documents or that unknown conditions existed in the site. Based on the owner's judgment, he shall make an equitable adjustment to the contract sum and duration. If the owner does not see that such conditions are material, he should inform the design-builder promptly of that, stating his reasons. Although there is no solid period for the owner to issue such rejection decision, which is risky the design-builder, it is expected that owners do not have an interest in delaying their projects. This means that the owner will be encouraged to make prompt replies to the design-builder. Human remains, burial markers, archeological sites, and wetlands are treated the same way as the unknown site conditions.

If hazardous material is discovered in the site, and such material was not part of the contract, the owner shall bear the costs of hiring a licensed laboratory for testing the nature of the material. Before hiring such entity, he shall notify the design-builder of it and make sure that the design-builder does not have an objection to it. The owner is then responsible for removing the hazardous material and indemnifying all other parties of any caused damages. If this process causes additional costs and delays to be incurred on the design-builder, he becomes entitled for such additional costs and extension of time.

5.8.1.4 Personnel

In the contract, the owner must set the person that will be his representative. Such person shall have authority to bind the Owner in all matters requiring the Owner's approval. This is standard in almost all contracts.

The contract allows the design-builder to change key personnel, sub-contractors, and suppliers. However, the owner must approve such changes first. The contract gives the owner 14 days to approve or reject the design-builder’s request of making such change. In case of rejection, in part or in full, the owner must provide reasons for such rejection. Within these 14 days, the owner could request additional time for review. If the owner does not reply to the design-builder’s request, he is considered to be approving it under the contract.

5.8.1.5 Site Work

If the owner performs construction related to the site using his own task force or using another contractor, he shall inform the design-builder of that. The design-builder shall cooperate with the other contractors within his scope. The owner is obliged to make equitable adjustments to the contract sum and duration in case such works interfere negatively with the works of the design-builder.

If the owner observes or becomes aware of a default or a defect in the work, he shall promptly notify the design-builder of such non-conformity. Acting lately in such situations would be considered bad faith. It is the author's opinion that a time limit should be set for the owner to report non-conformities to prevent any acts of bad faith from his side. The word "promptly" is not solid enough.

The owner has the right to visit the site; however, site visits shall not be made to obstruct the flow of work, neither to check the quality or quantity of the work. The owner also does not have the right to control the construction methods and procedures. He also does not have control of the safety precautions and programs in connection with the work. Moreover, he is obliged to obtain easements, zoning variances, and legal authorizations regarding site utilization so that the design-builder can have access the site.

The owner is obliged to pay for the tests and inspections that do not become requirement until after bids are received or negotiations concluded. However, if those tests reveal failure of the tested work to comply with the contract requirements, the costs of such tests and the costs for fixing the failure are borne by the design-builder.

5.8.1.6 Proof of Financial Security

According to article 7.2, the owner shall provide the information and services required from him (as agreed between the parties) with reasonable promptness. Although this "reasonable promptness" does not make any time guarantees to the design-builder, the owner is expected to furnish such information and services promptly since he does not have any interest in delaying his project.

If the design-builder requests that the owner provide evidence that the latter's financial arrangements are sufficient to make the payments to the design-builder, the owner shall furnish such evidence. The contract did not state the period that the owner should provide such information through. Also, if the owner submits such information, he shall not make any material changes to his financial arrangement before prior notice to the design-builder. Article 7.2.7 states the conditions at which the design-builder is entitled to request the mentioned evidence from the owner. However, the contract does not explicitly state what is the design-builder's right if the owner does not furnish the requested financial safety documentation.

5.8.1.7 *Timely Review of Submittals and Requests*

Article 3.1.11.1 states that the owner shall review submittals and requests made by the design-builder within the time set in the submittal schedule. The submittal schedule is a document that is prepared by the design-builder at the beginning of the project or before a series of submittals listing the dates of the expected submittals and the dates at which the owner is obliged to reply to such submittals. The owner must approve such schedule before it becomes enforceable. In this case, if the owner approves a submittal later than the assigned time in the submittals schedule, the design-builder will be entitled for an extension of time or/and increase in the contract sum depending on the impact of the delay. The contract did not state exactly the period limit that the owner should not exceed to approve this schedule though. In case the design-builder does not submit a submittals schedule, he will not be entitled for an extension of time or increase in the contract sum in case of the owner's late approval of submittals, because there is nothing that defines "late" in this case.

When an event giving rise to a claim for increasing the contract sum or the time for completion by the design-builder, the design-builder shall submit a notice of that claim within 21 days of the data where such event took place. Within 10 days of receiving such notice, the owner shall inform the design-builder of his initial decision of either requesting additional supporting data from the design-builder, withdrawing the claim in whole or in part, approving the claim, suggesting a compromise, or indicating that he is unable to render an initial decision because he lacks sufficient information to evaluate the merit of the claim. The contract does not state what happens if the owner does not make his initial decision within 10 days of receiving the notice for claim; which adds to the ambiguities of the contract.

5.8.1.8 *Safety*

In this contract, the design-builder is solely responsible for the site's safety. The contract is silent on the owner's rights or obligations if he becomes aware of the design-builder's non-compliance with safety. However, such compliance could be treated as other types of compliances and could lead to termination. Other contracts have more details regarding the owner's role in safety.

5.8.1.9 <u>Insurance</u>

Under this contract, the owner has the obligation to purchase and maintain four different types of insurance to protect himself, the design-builder, architect, consultants, and subcontractors. The insurance policies are:

1. Owner's liability insurance: which protects the owner from claims arising from damage or hazard caused by him.
2. Property insurance: This includes "*insurance against the perils of fire (with extended coverage) and physical loss or damage including, without duplication of coverage, theft, vandalism, malicious mischief, collapse, earthquake, flood, windstorm, falsework, testing and startup, temporary buildings and debris removal, including demolition occasioned by enforcement of any applicable legal requirements, and shall cover reasonable compensation for the Design-Builder's services and expenses required as a result of such insured loss*."
3. Boiler and machinery insurance; which covers commissioning, testing, or breakdown of equipment.
4. Loss of use insurance: This is optional. This insures the owner against loss of use of the property due to fire or other hazards, however caused; even if caused by the design-builder.

5.8.1.10 <u>Suspension and Termination</u>

The owner has the right to suspend the project and is obliged to compensate the design-builder for the work performed prior to the owner's notice of suspension. The contract did not put restrictions on the owner in terms of "how many days should the suspension notice be sent prior to the actual suspension?". The owner shall note that if the suspension lasts for more than 90 cumulative days, the design-builder has the right to terminate the contract by giving a seven-day notice. However, if the suspension was caused by a default by the owner, and lasted for more than 60 days, the design-builder may terminate the agreement after a seven-day notice from the end of the 60 days.

As for termination, the contract gives the right to the owner to terminate the agreement if the design-builder substantially fails to perform in accordance to the terms of the agreement. The termination in this case takes place after no less than seven days from the owner's notice of termination. The contract also gives the owner the right to the terminate the agreement for his convenience without cause upon giving the design-builder a seven-day notice.

5.8.2 "Other" Conditions Related to Owner's Obligations Under the ConsensusDOCS 410 Contract

5.8.2.1 Permits

Prior to construction, the owner must obtain the necessary site access approvals that enable the design-builder to use and occupy the site.

The Design-Builder shall obtain, and the Owner shall pay for, all planning permits necessary for the construction of the Project.

5.8.2.2 Design Documents

In the ConsensusDOCS, the owner shall provide an Owner's Program at the beginning of the design phase. This Owner's Program is defined in Article 2.4.11 as "*an initial description of the Owner's objectives, that may include budget and time criteria, space requirements and relationships, flexibility and expandability requirements, special equipment and systems, and site requirements*."

5.8.2.3 Site Conditions

Without needing the design-builder's request, the owner shall provide all available information describing the site including surveys, legal descriptions, existing conditions, subsurface studies, environmental studies, reports, and investigations.

If hazardous material is discovered in the site, and such material was not part of the contract, the owner shall bear the costs of testing the nature of the material and the corrective action to removing such material. He does not need to have the design-builder's approval on the entities who will do the testing or removal of the hazardous material. If this process causes additional costs and delays to be incurred on the design-builder, he becomes entitled for such additional costs and extension of time.

If the design-builder finds concealed or sub-surface conditions that are materially different from what is reasonably anticipated, he is entitled to claim additional cost and/or time. Such process is in the form of a "claim for additional cost or time". In such claims, the owner shall respond with 14 days of receiving the claim documentation from the design-builder.

5.8.2.4 Personnel

As in almost all contracts, the owner's representative's name must be written in the contract. Such person shall have authority to bind the Owner in all matters requiring the Owner's approval.

5.8.2.5 Site Work

The owner shall provide inspection and testing services during construction as required by law. Similar to the provisions of the AIA, under the ConsensusDOCS, if the owner becomes aware of a default or a defect in the work, he shall promptly notify the design-builder of such non-conformity.

5.8.2.6 Proof of Financial Security

Similar to the AIA, the ConsensusDOCS obliges the owner to provide full information regarding requirements for the project in a timely manner. Although "timely manner" does not give the design-builder relief on when exactly the owner will provide such information, it is unlikely that owners intend to delay their projects. So, owners will be keen to provide the needed information in a timely fashion.

Similar to the conditions of the AIA contract, in the ConsensusDOCS, if the design-builder requests that the owner provide evidence that the latter's financial arrangements are sufficient to make the payments to the design-builder, the owner shall furnish such evidence. However, unlike in the AIA contract, here, the design-builder can only make this request prior to commencement of work. If the owner intends to make any material change in his financing arrangement, he shall notify the design-builder of such change beforehand. The contract does not explicitly state what is the design-builder's right if the owner does not furnish the requested financial safety documentation.

5.8.2.7 Timely Review of Submittals and Requests

Several submittals are expected from the design-builder, such as schematic design documents, preliminary estimates, and construction documents. The design-builder might also have requests throughout the project period. The owner shall review and timely approve the design-builder's submittals. The contract did not specify a certain time limit for such review process. However, in another article, the contract stated that the design-builder shall submit a "Schedule of the Work" to the owner. Among the other content of the schedule is the dates when information and approvals are required from the owner. The owner shall review and approve such schedule in a timely manner.

In cases of claims for additional time or compensation made by the design-builder, the owner shall respond within 14 days of receiving the claim documentation from the design-builder. It should be noted that the claim documentation is different than the notice of claim. Under the ConsensusDOCS, the design-builder shall submit a notice within 21 days of the event giving rise to the event takes place. Within 14 days of owner receiving the notice for claim, the design-builder submits the supporting documentation for such claim. Failure of the owner to reply within those 14 days deem the design-builder's claim denied. If the claim is approved, then the owner shall issue a change order including the changes in completion data or compensation. In case of a change order that is requested by the DB, there is no governing period for the owner to review and approve the requested change order; which is not strange relevant to other standard forms of contract.

5.8.2.8 Safety

Safety is the responsibility of the design-builder. However, unlike the AIA, the ConsensusDOCS gives the owner the right to interfere in case becomes knowledgeable of safety risks on site. According to article 3.5.6, "*If the Owner deems any part of the Work or Worksite unsafe, the Owner, without assuming responsibility for the Design-Builder's safety program, may require the Design-Builder to stop performance of the Work or take corrective measures satisfactory to the*

Owner, or both. If the Design-Builder does not adopt corrective measures, the Owner may perform them and reduce by the costs of the corrective measures the amount of the GMP".

5.8.2.9 *Insurance*

The contract specifies that the owner must purchase a Builder's Risk Policy insurance before the start of the work. The named insureds in this policy are to be the owner, Design-Builder, Subcontractors, Sub-subcontractors, Material Suppliers and Architect/Engineer. According to article 11.3, this insurance "*cover all risks of physical loss except those specifically excluded by the policy, and shall insure at least against the perils of fire, lightning, explosion, windstorm, hail, smoke, aircraft (except aircraft, including helicopter, operated by or on behalf of Design-Builder) and vehicles, riot and civil commotion, theft, vandalism, malicious mischief, debris removal, flood, earthquake, earth movement, water damage, wind damage, testing if applicable, collapse however caused, and damage resulting from defective design, workmanship or material, and material or equipment stored offsite, onsite or in transit*."

The contract also gives the owner the option not to purchase the builder's risk policy. However, in this case, he must inform the architect/engineer and the design-builder. The design-builder may then purchase such insurance to protect his interests. If he does so, the cost of the insurance shall be charged to the owner; and the owner will be responsible for all other costs attributed to his neglect in purchasing the policy. Accordingly, it is better for the owner to just purchase the insurance policy since he is paying for it in all cases.

There are two other types of insurance that the owner may purchase. The contract states them but does not oblige the owner to purchase them. The two insurances are the "business income insurance" and the "owner's liability insurance". The business income insurance is against loss of use of the owner's property caused by fire or other casualty loss. The owner's liability insurance is for the owner to protect himself from claims out of his non-compliance with the contract documents.

5.8.2.10 Suspension and Termination

The owner has the right to suspend the project either for convenience or due to any default caused by the design-builder. The contract did not put restrictions on the owner in terms of "how many days should the suspension notice be sent prior to the actual suspension?". The owner shall note that if the suspension that is requested or caused by him lasts for more than 30 cumulative days, the design-builder has the right to terminate the contract by giving a seven-day notice. This is much shorter than the period granted by the AIA contract.

Similar to the AIA contract, the ConsensusDOCs contract gives the right to the owner to terminate the agreement if the design-builder substantially fails to perform in accordance to the terms of the agreement. Such defaults are stated in Article 12.2.2. However, the contract did not state the period that should be given between the owner's notice of termination and the actual termination of the agreement.

5.8.3 "Other" Conditions Related to Owner's Obligations Under the EJCDC D-700 Contract

5.8.3.1 Permits

The owner is obliged to provide permits, licenses, and approvals for enabling the design-builder to access and use the site. However, all other permits, licenses, and approvals of government authorities having jurisdiction over the project are the sole responsibility of the design-builder. The owner's role in such permits is just providing assistance in filing the requested documents.

5.8.3.2 Design Documents

The EJCDC refers to the design documents required from the owner as the "Conceptual Documents". It defines the conceptual documents in Article 1.01.8 as "*The drawings and specifications and/or other graphic or written materials, criteria and information concerning Owner's requirements for the Project, such as design objectives and constraints, space, capacity and performance requirements, flexibility and expandability, including those items enumerated in the Request for Proposals which show or describe the character and scope of, or relate to, the Work to be performed or furnished and which have been prepared by or for Owner*."

5.8.3.3 *Site Conditions*

While furnishing the site to the design-builder, the owner shall notify the design-builder of any unusual encumbrances or restrictions that the latter must be knowledgeable of so that he makes his plans accordingly. The owner is also obliged to obtain - in a timely manner - and pay for easements for permanent structures or permanent changes in existing facilities. If the parties disagree on the cost of such easements and changes, and this disagreement resulted in delaying the design-builder's work, or if the design-builder is delayed due to the owner's delay in furnishing the site, the design-builder has the right to claim for extension of time and/or extension of time. As such, owners must be keen to furnish the site as early as possible, and it is even better to agree on the costs of any easements or demolition early.

The design-builder has the right to request a statement of record legal title and legal description of the lands upon the construction is to take place. The owner shall furnish this statement within a reasonable time from the date of the design-builder's request.

The owner must provide information that is needed by the design-builder to execute the works in the site such as site boundaries, topographic surveys, utility surveys, zoning, land use restrictions, subsurface investigation results, and environmental assessments. The details of when to submit such documents are not explicitly stated in the contract though. However, Article 8.01 states that such documentation should be submitted in a timely manner so as not to delay the services of the design-builder.

According to Article 4.02 A, the design-builder shall notify the owner of *"(i) subsurface or latent physical conditions at the Site which differ materially from those indicated in the Contract Documents, or (ii) unknown physical conditions at the Site, of an unusual nature, which differ materially from those ordinarily encountered and generally recognized as inhering in work of the character called for by the Contract Documents*". He shall make the notification promptly after discovering such differing conditions, and before such conditions are disturbed. Promptly after receiving the notice, the owner must investigate the site conditions and adjust the contract sum and time if the conditions were in fact materially different than what was stated in the contract or reasonably expected by the parties.

If hazardous material is discovered in the site, and such material was not part of the contract, the owner shall bear the costs of testing the nature of the material and the corrective action to removing such material. He does not need to have the design-builder's approval on the entities who will do the testing or removal of the hazardous material. If this process causes additional costs and delays to be incurred on the design-builder, he becomes entitled for such additional costs and extension of time.

5.8.3.4 Personnel

As standard in all contracts, the owner must specify the person to act as the owner's representative. Such person has the complete authority to act on behalf of the owner. There is no explicit clause stating the owner's right to request any changes in the design-builder's personnel.

5.8.3.5 Site Work

The owner shall not supervise, direct, or have control or authority over the design builder's means, methods, techniques, sequences, or procedures of construction according to Article 8.03.

If the owner becomes aware of a default or a defect in the work, he shall promptly notify the design-builder of such non-conformity. The cost of correcting the defective parts are borne on the design-builder.

As for testing and inspections that are required by the public bodies having jurisdiction on the site, the design-builder is obliged to arrange and obtain such inspections, tests or approvals, pay all relevant costs, and submit to the owner the required certificates of inspection or approval. As for the inspections required for the owner's approval of the work, the design-builder is also responsible for arranging and paying for those tests. Moreover, the design-builder is the one that provides the schedule for the needed inspections by the owner. The owner has the right to request uncovering covered construction for testing. If the tests show that the uncovered part is not defective, the owner is obliged to compensate the design-builder for the lost time and all other added costs in addition to an increase in the contract duration if applicable. On the other hand, if the uncovered work was defective, the design-builder bears all relevant cost of fixing the defect and is not entitled to additional compensation or extension of time.

5.8.3.6 *Proof of Financial Security*

Similar to the AIA and ConsensusDOCS mentioned earlier, the EJCDC states that the owner shall provide evidence to the design-builder that sufficient funds are available and committed for the entire cost of the project, if requested by the design-builder. The contract did not state exactly when, or under what conditions, the design-builder makes such request. This implies that the design-builder can make this request at his convenience. This contract states that the design-builder has the right to stop work if such evidence is not provided to him within a reasonable time, upon 15 days notice to the owner. The previously mentioned AIA and ConsensusDOCS contract did not explicitly state this right of stopping work in case of the owner' non-response to the design-builder's request. As such, this contract is seen to be more "caring" to the design-builder in this point than the AIA and the consensusDOCS.

5.8.3.7 *Timely Review of Submittals and Requests*

Within 10 days after the contract's commencement date, the design-builder submits a preliminary schedule of submittals showing the times for the expected submittals and the times needed for reviewing and processing each of them by the owner. The contract did not state the period at which the owner is required to approve such schedule. The owner shall review and approve submittals in accordance with the approved schedule of submittals. There is no explicit article stating what happens if the owner does not abide by the times in the schedule of submittal. However, in this case, the design-builder could use Article 11.02.B (claiming a change in the contract time) on the basis that the owner's failure to abide by the schedule of submittals is an "act of neglect by the owner" that led to delays beyond the design-builder's control.

In cases of claims for additional time or compensation made by the design-builder, the owner shall respond within 30 days of receiving the claim documentation from the design-builder. Under the EJCDC, the design-builder can send a notice of claim then supporting documentation no later than 15 days after such notice. The contract did not explicitly state what happens if the owner fails to respond within the 30-day limit.

5.8.3.8 *<u>Safety</u>*

Article 8.03 explicitly states that the "*The Owner shall not supervise, direct, or have control or authority over, nor be responsible for, Design/Builder's .... safety precautions*". The design-builder has the sole responsibility on the safety of the construction site. There is no clause that explicitly states the owner's rights or obligations if he becomes knowledgeable of safety risks on site though.

5.8.3.9 *<u>Insurance</u>*

In this contract, the owner's liability insurance is optional. The owner "may" purchase and maintain an owner's liability insurance to protect himself against claims which may arise from operations under the contract. However, the contract obliges the owner to purchase and maintain property insurance upon the construction in the amount of the full replacement cost. This insurance also shall include testing and startup.

5.8.3.10 *<u>Suspension and Termination</u>*

The owner has the right to suspend the project without cause. The contract did not put restrictions on the owner in terms of "how many days should the suspension notice be sent prior to the actual suspension?". The contract states that the design-builder will fix the date on which work will be resume and shall resume the work on that date. The owner shall note that if the suspension that is requested or caused by him lasts for more than 90 days, the design-builder has the right to terminate the contract by giving a seven-day notice.

As for termination, the contract gives the right to the owner to terminate the agreement if the design-builder substantially fails to perform in accordance to the terms of the agreement (stated in Article 14.02). The termination in this case takes place after no less than seven days from the owner's notice of termination. The EJCDC explicitly states that, in case a notice of termination was sent to the design-builder for the purpose of termination due to his default, the termination shall not take place if he took corrective actions within 7 days of receiving the notice. If the corrective actions still do not cure the failure within 30 days of the design-builder receiving the notice of termination, the owner has the right to terminate the agreement. The contract also gives the owner the right to the terminate the agreement for his convenience without cause upon giving the design-builder a seven-day notice.

5.8.4 "Other" Conditions Related to Owner's Obligations Under the FIDIC Yellow Book

5.8.4.1 Permits

The owner's role is to assist the design-builder in obtaining copies of the laws of the country hosting the project and assist him applying for the required permits, licenses, and approvals from the entities that have jurisdiction over the project. The design-builder is the party that is actually responsible for the permits. The contract does not state that the owner is liable to apply for any permits. However, he is liable for giving the design-builder access to the site. So, it could be implied that the owner is responsible for any permits that ensure the design-builder's access to the site.

5.8.4.2 Design Documents

The "employer's requirements" is defined in Clause 1.1.1.5 as the document specifying the "*purpose, scope, and/or design and/or other technical criteria, for the works*". This document is part of the contract documents and is the one followed by the design-builder to guide his designs and construction.

5.8.4.3 Site Conditions

The owner shall give the contractor the access to the construction site at the time needed for the design-builder to start the work. The owner has the right to abstain from giving the design-builder access to site until the former has received the performance security from the latter. The design-builder is entitled to claim for extension of time and additional compensation if the owner is delayed in giving him access to site. The owner shall also provide surveying positioning points and levels and be responsible for any errors in these specified items. If the design-builder suffers any delays or added costs due to errors in the point of reference that were provided by the owner, and if such errors could not have been reasonably anticipated by his experience as a professional contractor, he will have the right to claim for additional compensation and extension of time.

The owner should furnish all available data regarding sub-surface conditions and hydrological conditions, prior to 28 days from the design-builder's submission of the tender. However, the language of the contract indicates that it is acceptable if the owner does not furnish such information, given that he does not have them. The FIDIC is different than other contracts in the way that it allocates some risks of differing site conditions on the design-builder rather than the owner. Article 4.10 states that the design-builder "*shall be deemed to have inspected and examined the site, its surroundings, the above data and other information ... including ... sub-surface conditions*". If the design-builder discovers differing site conditions that result in delays and added cost, he has the right to claim for additional compensation and extension of time. However, the engineer has an authority to make a counter-claim that such differing conditions should were foreseeable by the design-builder and should have appeared in the design-builder's tests as per the abovementioned Article 4.10. In relation to the other contracts, the FIDIC puts more risk on the design-builder when it comes to differing site conditions.

5.8.4.4 Personnel

The FIDIC Yellow book states the owner's personnel must cooperate with the contractor [Article 2.3 and Sub-clause 4.6]. Other contracts do not necessarily state that. The owner shall appoint an engineer to issue instructions to the design-builder and partake in several other defined tasks. The engineer is set in the contract. If the owner intends to replace the engineer, he shall give notice to the design-builder of the information and experience of the indented replacement engineer no less than 42 days before the intended date of replacement. Not only this, the owner shall not hire the replacement engineer if the design-builder raises reasonable objection against him via a notice accompanied with particulars. Many of the owner's obligations in the other forms of contract are transferred to the engineer in the FIDIC Yellow Book. For example, the engineer is the party responsible foe determining the reasonable amount for any extension of time or additional compensation. He is also the party insuring that the owner's design requirements are satisfied. The engineer is also the party responding to the design-builder's requests (not all kinds of requests) and submissions.

5.8.4.5 Site Work

Since the FIDIC requires the design-builder to submit a performance security to the owner at the beginning of the project, the owner is obliged to return such security within 21 days after receiving a copy of the performance certificate from the engineer. The performance certificate is a certificate issued by the engineer to certify that the design-builder has completed its obligations under the contract.

The design-builder is also responsible for arranging and paying for costs of tests and inspections. Moreover, the design-builder is the one that provides the schedule for the needed inspections by the engineer. The owner has the right to request uncovering covered construction for testing. If the tests show that the uncovered part is not defective, the owner is obliged to compensate the design-builder for the lost time and all other added costs in addition to an increase in the contract duration if applicable. On the other hand, if the uncovered work was defective, the design-builder bears all relevant cost of fixing the defect and is not entitled to additional compensation or extension of time.

The owner shall provide all needed resources – such as electricity and equipment – to perform the tests after completion. The owner shall perform such tests as soon as reasonably practicable after he takes over the works. He shall give to the design-builder 21 days' notice of the date after which the tests after completion will be carried out. These tests shall be carried out within 14 days after this date.

5.8.4.6 Proof of Financial Security

If the design-builder requests that the owner provide evidence that the latter's financial arrangements are sufficient to make the payments to the design-builder, the owner shall furnish such evidence within 28 days from receiving the design-builder's request. Also, if the owner submits such information, he shall not make any material changes to his financial arrangement before prior notice to the design-builder. If the owner intends to make any material change in his financing arrangement, he shall notify the design-builder of such change beforehand. The contract does not explicitly state what is the design-builder's right if the owner does not furnish the requested financial safety documentation. However, not abiding by the 28 days could be considered negligence from the owner's side and would have the contractual repercussions related to negligence.

5.8.4.7 Timely Review of Submittals and Requests

The engineer is the party responsible for reviewing submittals, requests, and even claims. As such, there are no special considerations or specific obligations for the owner regarding this matter. However, the owner must note that if the engineer's late replies caused delays to the design-builder, the design-builder is entitled to claim for additional compensation and extension of time; which is the owner's money and time.

5.8.4.8 Safety

The design-builder is the party responsible for the safety of the site and the personnel in the site. The contract is silent on the owner's right to notify the design-builder of any safety hazards that the former became knowledgeable of.

5.8.4.9 Insurance

The FIDIC Yellow Book does not oblige the owner to purchase and maintain insurance.

5.8.4.10 Suspension and Termination

The contract does not entitle the owner to directly suspend the work. This power is granted to the engineer. The engineer is the party that informs the design-builder of any desired suspension of work. However, given the important impacts of suspension, it is implicitly expected that the engineer would coordinate with the owner first before ordering the works to be suspended. As such, there are no "obligations" on the owner regarding suspension of work because the engineer is the party dealing with the design-builder regarding that matter. However, the owner shall be careful of the consequences of the engineer's actions. For example, if the suspension is continued for 84 days, the design-builder has the right to request the engineer's permission to proceed the work. If the engineer does not reply within 28 days of that request, the design-builder will have the right to terminate the contract as stated in Article 8.11.

If the design-builder fails to perform his duties or if he does one of the defective actions stated in Article 15.2, the owner has the right to terminate for cause upon giving a 14 day notice to the design-builder. However, in case the owner wants to terminate the contract without cause, his notice shall be within a period of 28 days, not 14 days.

5.8.5 "Other" Conditions Related to Owner's Obligations Under the JCT DB 2011 Contract

5.8.5.1 Permits

The JCT is silent when it comes to permitting. As such, parties must be careful to draft any clauses related to permitting obligations in the particulars.

5.8.5.2 Design Documents

Under this contract, the owner submits to the design-builder the "Employer's Requirements" that define the needed work from the design-builder such as the scope, design criteria, and specifications. These are the requirements at which the design-builder bases his price and schedule on. They are also the basis for evaluating whether his work is satisfactory. The contract clearly states that the design-builder is not responsible for verifying the adequacy of the employer's requirements.

5.8.5.3 Site Conditions

According to Article 2.9, the owner must define the boundaries of the site. But there are no provisions obliging the owner to provide other data such as sub-surface studies and hydrological studies.

There is are no clear provisions on what are the design-builder's entitlements in case there were differing conditions on the site. By analyzing clause 2.11 that states "*the design-builder shall not be responsible for the contents of the employer's requirements or for verifying the adequacy of any design contained with them*" and clause 2.12 that states "*if an inadequacy is found in any design in the employer's requirements in relation to which the design-builder is not responsible for verifying its adequacy …. Any relevant correction or alteration shall be treated as a Change*", the following could be concluded implicitly: (1) the owner does not have to provide the subsurface information; (2) if the owner provided the subsurface information as part of the “Employer’s Requirements” and there appeared to a conflict between the actual site conditions and what was submitted by the owner, the design-builder may be entitled for a change order modifying the contract sum and the time for completion, but still this is not a guaranteed right because it is not explicitly stated; and (3) if the owner does not submit the subsurface information, and the site conditions did not match what was expected by the design-builder, the design-builder will not be entitled for a change in the contract sum or the time for completion. As such, the risks are transferred to the design-builder, and there are really no significant obligations regarding the site conditions on the owner.

5.8.5.4 Personnel

Similar to the rest of the contracts, the JCT obliges the owner to identify the person who will act as the owner’s representatives and have all authorities of the owner. The contract is silent on whether the owner has any rights or obligations regarding approving the design-builder’s site personnel.

5.8.5.5 Site Work

If the owner wishes to occupy the site or part of the site before the date of issuing the practical completion statement, he must take the consent of the design-builder first. If there the design-builder does not have any objection to that, he should notify the owner of his consent within a reasonable time.

When the design-builder achieves practical completion of the works, or a section of the works, the owner is obliged to issue a “practical completion statement”. This is an important document because final payments are based on it. Despite its importance, the contract did not specify the period that the owner should abide by for issuing this statement. Article 2.27 defines what constitutes practical completion by the design-builder. If the design-builder fails to complete the work or the section of work by the relevant approved completion date, the owner is obliged to issue a “non-completion notice”. Still, the contract does not specify any time limitations for the owner to issue such notice. It does not even say that he shall submit it within a reasonable time.

The contract differentiates between written and non-written instructions. As other contracts, the JCT enforces written instructions and does not consider non-written instructions binding. However, it alerts the owner that if he issues a non-written instruction, he has to confirm it in writing within 7 days or else such instruction in not binding.

As in the majority of contracts, under the JCT, the owner has the right to request uncovering covered construction for testing. If the tests show that the uncovered part is not defective, the owner is obliged to compensate the design-builder for the lost time and all other added costs in addition to an increase in the contract duration if applicable. On the other hand, if the uncovered work was defective, the design-builder bears all relevant cost of fixing the defect and is not entitled to additional compensation or extension of time.

5.8.5.6 Proof of Financial Security

The contract does not oblige the owner to provide evidence proving sufficiency of funds to the design-builder. In other words, it is silent regarding this mater. This is risky to the design-builder as there are no proofs that the owner actually has the sufficient financial arrangements to make the payments to the design-builder.

5.8.5.7 Timely Review of Submittals and Requests

Excusable or non-excusable circumstances may take place the lead to delays in the work. Article 2.24 give the design-builder the right to notify the owner of those circumstances. Shortly after sending the notice, the design-builder shall give particulars of the expected effects of those circumstances including an estimate of any expected delay in the date of completion. The owner is obliged to notify the design-builder of his decision – of whether an extension of time is granted or not - as soon as reasonably practicable and no later than 12 weeks of receiving the relevant particulars from the design-builder; given that the period between the date of sending the particulars and the approved completion date is more than 12 weeks. In all cases, the owner's decision needs to be made prior to the completion date. As for all other non-payment requests, the owner has the obligation to reply to them within a reasonable time.

5.8.5.8 Safety

Under this contract, the parties shall endeavor to establish and maintain a working environment in which health and safety is of paramount concern. The contract states that the design-builder shall be responsible for abiding by the regulations put by the health and safety executive. But it does not define who is this party and how it is appointed. The JCT is not as clear as the other contracts when it comes to safety. There is no explicit clause that makes any party the sole responsible for the safety of the personnel on site. There are also no clauses that describe the owner's rights/obligations if he became knowledgeable about safety risks on site.

5.8.5.9 Insurance

For the erection of new buildings, the contract does not oblige the owner to purchase an insurance policy. All insurance policies in this case shall be purchased and maintained by the design-builder. This is what is referred to as Option A. There are two more insurance options set by the contract and to be agreed upon by the parties depending on the type of work. According to the footnotes of Article 6.7, "*Insurance Option A is applicable to the erection of new buildings where the Contractor is required to take out a Joint Names Policy for All Risks Insurance of the Works and Insurance Option B is applicable where the Employer has elected to take out that Joint Names Policy. Insurance Option C is for use in the case of alterations of or extensions to existing structures; under it, the Employer is required to take out a Joint Names Policy for All Risks Insurance for the Works and also a Joint Names Policy to insure the existing structure and their contents owned by him or for which he is responsible against loss or damage by the Specified Perils.*"

5.8.5.10 Suspension and Termination

If, due to default by the design-builder (stated in Article 8.4), the owner wishes to terminate the contract, he shall send a notice specifying such default(s) and give the design-builder a chance for 14 days to fix such default(s). If the design-builder continues the default(s) for 14 days from receiving the owner's notice, the owner "*may on, or within 21 days from, the expiry of that 14 day period by a further notice to the design-builder terminate the agreement*" [Article 8.4.2]. In cases of design-builder's insolvency or corruption, the owner has the right to directly terminate the contract with just a single notice without any period. The language and organization of the JCT makes it difficult for inexperienced contract administrators to identify the design-builder's right for compensation in cases of termination due to his default. The contract is not clear on the termination for convenience.

The contract does not provide a mechanism for the owner to suspend the work. It doesn't answer the question: if the owner wishes to suspend the work, when shall he send the notice of suspension to the design-builder? Either party, may upon expiry of the specified period of suspension give notice to the other that, "*unless the suspension ceases within 7 days after the date of receipt of that notice, he may terminate the agreement*" [Article 8.11.1]. In this case, the contract clearly states the mechanism of how the design-builder is compensated in this case in Article 8.12.

5.8.6 "Other" Conditions Related to Owner's Obligations Under the NEC3 Engineering and Construction Contract

Similar to the FIDIC, the NEC3 necessitates that a third party be hired to manage communication with the design-builder on behalf of the owner, as well as to take care of determinations, approvals, and requests. The NEC3 names this party "The Project Manager".

5.8.6.1 Permits

The NEC3 is silent when it comes to permitting. As such, parties must state the rights and responsibilities of permitting in the particulars to prevent ambiguities.

5.8.6.2 Design Documents

The main document stating the design-builder's scope of work is defined in the NEC3 as the "Works information". According to Article 11.19, works information is "*information which either: (1) specifies and describes the works or, (2) states any constraints on how the Contractor Provides the Works; and is either (1) in the documents which the Contract Data states it is in or (2) in an instruction given in accordance with this contract.*"

5.8.6.3 <u>Site Conditions</u>

The NEC3 defines a document named "Site Information" as "*information which (1) describes the Site and its surroundings and (2) is in the documents which the Contract Data states it is in*." However, it does not exactly state what type of site information it is. Does this information include subsurface conditions? Does it include hydrological studies? The contract is silent on that. As such, the contractor might be at risk of not receiving enough information on the site. If the design-builder finds the site conditions substantially different than what was provided in the "site information" document, he is entitled for additional compensation and extension of time based on the project manager's judgement.

5.8.6.4 <u>Personnel</u>

The owner does not have any obligations regarding approving the design-builder's personnel. Such obligations are transferred to the project manager.

5.8.6.5 <u>Site Work</u>

The contract states that the owner must allow access to and use of the site to the design-builder before the access dates that are agreed upon between the parties and written in the contract. Although not stated explicitly, it could be implied that the owner is responsible for obtaining the permits that enable the design-builder to access and use the site.

The NEC3 allocates the responsibility and associated costs of doing the tests and inspections on both the owner and the design-builder, unlike other contracts. The exact details of such responsibility should be agreed upon by the parties and stated in a document named "Works Information" in the contract.

5.8.6.6 <u>Proof of Financial Security</u>

The contract does not oblige the owner to provide evidence proving sufficiency of funds to the design-builder. In other words, it is silent regarding this mater. This is risky to the design-builder as there are no proofs that the owner actually has the sufficient financial arrangements to make the payments to the design-builder.

5.8.6.7 <u>Timely Review of Submittals and Requests</u>

There are no significant obligations on the owner regarding the contractor's submittals and requests. The project manager is the party responsible for such communication endeavors.

5.8.6.8 <u>Safety</u>

The NEC3 states that the design-builder is responsible for the health and safety endeavors on the site. There are no obligations on the owner regarding this area.

5.8.6.9 <u>Insurance</u>

If the owner provides plant and materials, the contract states that he is responsible for purchasing an insurance policy against their loss and damage. The rest of the insurance is covered by the design-builder as stated in Article 84 of the contract.

5.8.6.10 <u>Suspension and Termination</u>

In the NEC3, the project manager is the party that is responsible for handling the process of suspension and termination.

5.8.7 Summarized Comparative Analysis of "Other" Conditions Related to Owner's Obligations

Table 5.3 summarizes the key elements of the provisions related to owner's other obligations in the analyzed contracts. This enables easy comparison between the different contracts with regards to the points of analysis. Table 5.3 is similar in concept to Table 5.1 but with a difference in focus. Table 5.1 is concerned with the owner's payment obligations while Table 5.3 is concerned with the rest of the owner's obligations including permits, design documents, site conditions, personnel, site work, proof of financial security, timely review of submittals and requests, safety, insurance, suspension, and termination.

Table 5.3. Comparison between Standard Forms of Contract (Owner's "Other" Obligations)

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
Which party is responsible for applying for and obtaining permits from government authorities.	Design-builder.	Design-builder. But the owner shall pay for all these permits.	Design-builder.	Design-builder.	The contract is silent regarding this matter. Parties must take care of this in the particulars.	The contract is silent regarding this matter. Parties must take care of this in the particulars.
The owner's obligations in the permitting process.	The owner is only obliged to obtain permits that enable the design-builder to access the site. For other permits, the owner's role is just assistance in the document-preparation process.	The owner is only obliged to obtain permits that enable the design-builder to access the site. For other permits, the owner's role is just assistance in the document-preparation process.	The owner is only obliged to obtain permits that enable the design-builder to access the site. For other permits, the owner's role is just assistance in the document-preparation process.	The owner is only obliged to obtain permits that enable the design-builder to access the site. For other permits, the owner's role is just assistance in the document-preparation process.	The contract is silent regarding this matter. Parties must take care of this in the particulars.	The contract is silent regarding this matter. Parties must take care of this in the particulars.
Design criteria (space requirements, functionality requirements, time and budget criteria, etc.)	The owner must submit design criteria to guide the design-builder and provide basis for evaluation. Such criteria are part of the document.	The owner shall provide an Owner's Program (which is the contract's naming for the design criteria) at the beginning of the design phase.	The Conceptual Documents (which is the contract's naming for the design criteria) are part of the contract documents.	The Employer's Requirements (which is the contract's naming for the design criteria) are part of the contract documents.	The Employer's Requirements (which is the contract's naming for the design criteria) are part of the contract documents.	The Works Information (which is the contract's naming for the design criteria) are part of the contract documents.
Access to site	The contract is silent regarding the owner's obligations in giving the design-builder access to use the site. However, in the US, the owner is obliged to do so under the "prevention principle" of the common law.	The contract is silent regarding the owner's obligations in giving the design-builder access to use the site. However, in the US, the owner is obliged to do so under the "prevention principle" of the common law.	The owner must allow access to and use of the site to the design-builder. The contract does not specify when this access shall be granted.	The owner shall give the design-builder the access to the construction site at the time needed for the design-builder to start the work. The owner has the right to abstain from giving the design-builder access to site until the former has received the performance security from the latter.	The owner must allow access to and use of the site to the design-builder before the access dates that are agreed upon between the parties and written in the contract.	The owner must allow access to and use of the site to the design-builder before the access dates that are agreed upon between the parties and written in the contract.
When the owner delays the design-builder from accessing the site.	The contract is silent regarding that. However, under the "prevention principle" of the common law, such delay would entitle the design-builder to time extension and compensation to cover resulting losses.	The contract is silent regarding that. However, under the "prevention principle" of the common law, such delay would entitle the design-builder to time extension and compensation to cover resulting losses.	The design-builder is entitled to claim for extension of time and additional compensation to cover his losses.	The design-builder is entitled to claim for extension of time and additional compensation to cover his losses.	The design-builder is entitled to claim for extension of time and additional compensation to cover his losses.	The design-builder is entitled to claim for extension of time and additional compensation to cover his losses.

Table 5.3. Continued. Comparison between Standard Forms of Contract (Owner's “Other” Obligations)

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
Is the owner obliged to provide site information (subsurface conditions, surveys, environmental studies, etc.) to the design-builder before execution?	Yes, but only if the owner has such information. The contract is silent on when this information is shall be furnished. If the owner does not have such information, then the design-builder has the right to request them. After this request, the owner must furnish the requested information at his own expense within a reasonable time.	Yes. But the contract is silent on when this information is shall be furnished.	Yes. But the contract does not explicitly state when such information should be provided.	Yes, but only if the owner has such information. If so, he shall furnish them prior to 28 days from the design-builder's submission of the tender.	Not obliged.	The contract is silent on that.
Discovering hazardous material that were not referred to in the contract	The owner shall bear the costs of hiring a licensed laboratory for testing the nature of the material. He shall take the design-builder's approval of the laboratory first. The owner is responsible for removing the hazardous material and indemnifying the design-builder for any corresponding damages through additional compensation, and/or extension of time.	The owner shall bear the costs of testing the nature of the material. The owner is responsible for removing the hazardous material and indemnifying the design-builder for any corresponding damages through additional compensation, and/or extension of time.	The owner shall bear the costs of testing the nature of the material. The owner is responsible for removing the hazardous material and indemnifying the design-builder for any corresponding damages through additional compensation, and/or extension of time.	The contract is silent regarding this matter.	The contract is silent regarding this matter.	The contract is silent regarding this matter.
Risk of differing site conditions is allocated on the …	Owner.	Owner.	Owner.	On the design-builder. By signing the contract, he shall be deemed to have inspected and examined the site, its surroundings, the above data and other information including sub-surface conditions.	The risk is on the design-builder if the owner does not furnish the site information. The is on the owner if he furnishes the site information.	The is on the owner if he furnishes the site information. If such information is not furnished by the owner, the contract is not clear on which party bears the risk of differing site conditions.

Table 5.3. Continued. Comparison between Standard Forms of Contract (Owner's “Other” Obligations)

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
In the contract, the owner shall state the person whom will have the authority to act on behalf of him.	Yes.	Yes.	Yes.	Yes. The owner also hires an engineer and writes his information in the contract. The engineer handles almost all communications with the design-builder and approvals. If the owner wishes to replace the engineer, he shall notify the design-builder 42 days before the replacement date, and he shall obtain the design-builder’s approval of the new engineer.	Yes.	Yes. The owner also hires a project manager and writes his information in the contract. The engineer handles almost all communications with the design-builder and approvals. The contract is silent on whether the owner needs the design-builder’s approval to change the project manager.
Does the design-builder need the owner’s approval if he wishes to change key personnel or sub-contractors on site?	Yes. The owner has 14 days from receiving such notice to respond. Failure to respond within the 14 days is considered as approval.	The contract is silent regarding this matter. This could be interpreted to the benefit of the design-builder; meaning that he does not need such approval from the owner.	The contract is silent regarding this matter. This could be interpreted to the benefit of the design-builder; meaning that he does not need such approval from the owner.	The contract is silent regarding this matter. This could be interpreted to the benefit of the design-builder; meaning that he does not need such approval from the owner.	The contract is silent regarding this matter. This could be interpreted to the benefit of the design-builder; meaning that he does not need such approval from the owner.	Yes. But the approval is needed from the project manager, not the owner. The contract does not state the period that the project manager should not exceed to approve the new key personnel.
Required tests and inspections.	The design-builder is responsible for arranging and paying for costs of tests and inspections.	The owner shall provide inspection and testing services during construction as required by law.	The design-builder is responsible for arranging and paying for costs of tests and inspections.	The design-builder is responsible for arranging and paying for costs of tests and inspections.	The design-builder is responsible for arranging and paying for costs of tests and inspections.	The NEC3 allocates the responsibility and associated costs of doing the tests and inspections on both the owner and the design-builder, the exact details of such responsibility should be agreed upon by the parties and stated in the “Works Information” document in the contract.

Table 5.3. Continued. Comparison between Standard Forms of Contract (Owner's "Other" Obligations)

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
Does the owner have to provide evidence of his financial ability to make payments to the design-builder?	Yes, within a reasonable period after the design-builder requests such information. The owner is not obliged to furnish such evidence if the design-builder does not request it.	Yes, within a reasonable period after the design-builder requests such information. The design-builder can make such request only prior to the commencement date. The owner is not obliged to furnish such evidence if the design-builder does not request it. The contract is silent on what is the owner's obligation if the design-builder makes such request after the commencement date.	Yes, within a reasonable period after the design-builder requests such information. The owner is not obliged to furnish such evidence if the design-builder does not request it.	Yes, within 28 days after the design-builder requests such information. The owner is not obliged to furnish such evidence if the design-builder does not request it.	The contract is silent regarding this matter.	The contract is silent regarding this matter.
In case the design-builder requests such evidence, and the owner does not provide it.	The contract is silent regarding this matter.	The contract is silent regarding this matter.	The design-builder has the right to stop work if such evidence is not provided to him within a reasonable time, upon 15 days' notice to the owner.	The contract is silent regarding this matter.	The contract is silent regarding this matter.	The contract is silent regarding this matter.
After submitting the evidence of financial security, is the owner obliged to obtain the design-builder's approval before making material changes to the owner's financial arrangements?	Yes. But the contract does not provide a time framework for that.	Yes. But the contract does not provide a time framework for that.	The contract is silent regarding this matter.	Yes. But the contract does not provide a time framework for that.	The contract is silent regarding this matter.	The contract is silent regarding this matter.
Are the design-builder's submittals scheduled?	Yes. The "submittals schedule" – which is submitted by the design-builder - lists the dates of the expected submittals and the dates at which the owner is obliged to reply to such submittals. The owner must approve such schedule before it becomes enforceable.	Yes. The "schedule of work" – which is submitted by the design-builder - lists the dates of the expected submittals and the dates at which the owner is obliged to reply to such submittals. The owner must approve such schedule before it becomes enforceable.	Yes. Within 10 days after the commencement date, the "schedule of submittals" shall be submitted by the design-builder. It lists the dates of the expected submittals and the dates at which the owner is obliged to reply to such submittals. The owner must approve such schedule before it becomes enforceable.	The owner is not required to review submittals. The engineer has this obligation.	The contract is unclear regarding this matter.	The owner is not required to review submittals. The project manager has this obligation.

Table 5.3. Continued. Comparison between Standard Forms of Contract (Owner's "Other" Obligations)

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
When is the owner obliged to reply to submittals and requests?	For scheduled submittals, the owner has to reply before the dates stated in the "submittals schedule". For unscheduled submittals and queries, the owner has to reply promptly. The exact "prompt" period is not stated.	For scheduled submittals, the owner has to reply before the dates stated in the "submittals schedule". For unscheduled submittals and queries, the owner has to reply promptly. The exact "prompt" period is not stated.	For scheduled submittals, the owner has to reply before the dates stated in the "submittals schedule". For unscheduled submittals and queries, the owner has to reply promptly. The exact "prompt" period is not stated.	Not applicable from an owner's obligation point. The engineer is the party responsible for replying to submittals and requests.	The owner shall reply within a reasonable time.	Not applicable from an owner's obligation point. The project manager is the party responsible for replying to submittals and requests.
Do late approvals, or replies, by the owner entitle the design-builder to claim extension of time and/or additional compensation?	Yes. If this delayed approval causes delays and/or losses to the design-builder.	Yes. If this delayed approval causes delays and/or losses to the design-builder.	Yes. If this delayed approval causes delays and/or losses to the design-builder.	Not applicable from an owner's obligation point. The engineer is the party responsible for replying to submittals and requests.	Yes. If this delayed approval causes delays and/or losses to the design-builder.	Not applicable from an owner's obligation point. The project manager is the party responsible for replying to submittals and requests.
When the owner receives a notice for a design-builder's claim for an extension of time and/or additional compensation, within how many days shall he reply?	Within 10 days of receiving such notice. However, the contract does not state what happens if the owner does not make his initial decision within 10 days of receiving the notice for claim	Within 14 days of receiving the claim documentation from the design-builder (which is different from the notice of claim). Failure of the owner to reply within those 14 days deem the design-builder's claim denied.	Within 30 days of receiving the claim documentation (which is different from the notice of claim) from the design-builder. The contract did not explicitly state what happens if the owner fails to respond within the 30-day limit.	Not applicable from an owner's obligation point. The engineer is the party responsible for replying to claims.	As soon as reasonably practicable and no later than 12 weeks of receiving the relevant particulars from the design-builder; given that the period between the date of sending the particulars and the approved completion date is more than 12 weeks	Not applicable from an owner's obligation point. The project manager is the party responsible for replying to claims.
The health and safety of the personnel on the site are which party's responsibility?	The design-builder.	The design-builder.	The design-builder.	The design-builder.	The design-builder shall be responsible for abiding by the regulations put by the health and safety executive. But the contract does not define who is this party and how it is appointed. There is no explicit clause that makes any party the sole responsible for the safety of the personnel on site. There are also no clauses that describe the owner's rights/obligations if became knowledgeable about safety risks on site.	The design-builder.
Does the owner have the right to fix any safety hazards on site if he becomes aware of them?	The owner is not obliged to do so. The contract is silent on whether the owner has the right to do so or not.	The owner is not obliged to do so. But he has the right to take corrective measures to eliminate the safety hazard and reduce the corresponding costs from his payments to the design-builder.	The owner shall not interfere with the design-builder's work in the site. He shall not have any authority over the safety precautions that are made in the site.	The owner is not obliged to do so. The contract is silent on whether the owner has the right to do so or not. But probably, if such right is granted implicitly, it would be granted to the engineer, not the owner.		The owner is not obliged to do so. The contract is silent on whether the owner has the right to do so or not. But probably, if such right is granted implicitly, it would be granted to the project manager, not the owner.

Table 5.3. Continued. Comparison between Standard Forms of Contract (Owner's “Other” Obligations)

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
What types of insurance is the owner obliged to purchase and maintain?	Owner' liability insurance, property insurance, boiler and machinery insurance, and loss of use insurance (optional).	Builder's risk policy insurance. If the owner does not purchase this insurance and the design-builder decides to purchase it, its cost will be assigned to the owner. Other optional insurances are the business income insurance and the owner's liability insurance.	Property insurance and owner' liability insurance (optional).	The contract does not oblige the owner to purchase insurance.	For the erection of new buildings, the contract does not oblige the owner to purchase an insurance policy. All insurance policies in this case shall be purchased and maintained by the design-builder.	If the owner provides plant and materials, the contract states that he is responsible for purchasing an insurance policy against their loss and damage. The rest of the insurance is covered by the design-builder.
The owner shall compensate the design-builder if the owner suspends the work?	Yes.	Yes.	Yes.	Yes. But the engineer is the party that suspends the work, not the owner.	Yes.	Yes. But the project manager is the party that suspends the work, not the owner.
How many days should the suspension notice be sent prior to the actual suspension?	Not stated.	Not stated.	Not stated.	Not applicable from an owner's obligation point of view because the engineer is the party that suspends the work, not the owner.	Not stated.	Not applicable from an owner's obligation point of view because the project manager is the party that suspends the work, not the owner.
What is the maximum number of consecutive suspension days before the design-builder has the right to terminate the agreement?	90 days.	30 days.	90 days.	84 days.	Not stated.	Not stated.
Termination by owner for cause.	The owner shall send a notice of termination to the design-builder no less than 7 days before the planned termination day.	The contract does not state the period that should be given between the owner's notice of termination and the actual termination.	The owner shall send a notice of termination to the design-builder no less than 7 days before the planned termination day.	The owner shall send a notice of termination to the design-builder no less than 14 days before the planned termination day.	The owner shall send a notice and give the design-builder a chance for 14 days to fix the default(s). If the design-builder continues the default(s) for 14 days from receiving the owner's notice, the owner may on, or within 21 days from, the expiry of that 14 day period by a further notice to the design-builder terminate the agreement. In cases of design-builder's insolvency or corruption, the owner has the right to directly terminate the contract with just a single notice without any period	The project manager is the party that is responsible for handling the process of suspension and termination.

Table 5.3. Continued. Comparison between Standard Forms of Contract (Owner's “Other” Obligations)

Comparison Criteria	AIA 141	ConsensusDOCS 410	EJCDC D-700	FIDIC Yellow Book	JCT DB2011	NEC3
Termination by owner for convenience.	The owner shall send a notice of termination to the design-builder no less than 7 days before the planned termination day.	The contract does not state the period that should be given between the owner’s notice of termination and the actual termination.	The owner shall send a notice of termination to the design-builder no less than 7 days before the planned termination day.	The owner shall send a notice of termination to the design-builder no less than 28 days before the planned termination day.	The contract is not clear on the termination for convenience.	The project manager is the party that is responsible for handling the process of suspension and termination.

5.8.8 Guidelines for Drafting “Other” Clauses Related to Owner’s Obligations

Table 5.4 presents a checklist that has been developed for the providing guidelines to drafting and administering provisions related to the owner’s other obligations. The checklist in Table 5.4 has 60 questions. The contract administrator should be able to answer all questions in the checklist to ensure that the contract is free of ambiguities and to ensure that he/she has proper understanding of the contract provisions related to the owner’s other obligations. In case a new contract is still being drafted, the checklist will aid such drafting process. The new contract should contain provisions that clearly answer those 60 questions. The developed checklist (Table 5.4) is only concerned with the owner’s obligations other than payment. It should be noted that, similar to Table 5.2, the questions in Table 5.4 assume that there are direct communications between the owner and the design-builder without having an architect or an engineer in between.

5.9 Outcomes and How They Relate to Dispute Mitigation

The provided comparative analysis and extensive guidelines will benefit owners and contractors in properly drafting, understanding, and administering their contracts. Focusing on the employer’s obligations in design-build construction contracts in this approach has not been tackled in relevant legal research. As such, this study will contribute to the body of knowledge and will promote efficient and effective administration of construction contracts. As such, disputes resulting from lack of understanding or ambiguity of employer obligation clauses will be avoided; which will have a positive effect on construction projects, the construction industry, and eventually the economy in general.

5.10 Recommendations for Future Work

For future work, it is recommended continuing the stream of analyzing provisions of design-build contract and forming extensive guidelines in the rest of the topics other than the owner’s obligations. Then, when such guidelines are complete, we recommend that legal experts use them to form a strong design-build standard form of contract that covers all the intended and non-intended shortcomings of the available standard forms of contract to further promote healthier contracting environment.

Table 5.4. Checklist for Drafting "Other" Clauses Related to Owner's Obligations.

Category	Questions Regarding Payment Provisions under Design-Build Projects
Permits	• What are the responsibilities of the different parties when it comes to preparing the documentation and applying for the different types of permits issued by the authorities having jurisdiction over the project? • What are the different types of permits that should be issued, and when? • What are the compensation arrangements for issuing the permits?
Design Documents	• Which document does the owner include all information about the design criteria, basis of evaluating the design-builder's design, and design milestones in? • When does the owner provide such information to the design-builder?

Site Conditions	• Is the owner obliged to provide site information such as hydrological studies, subsurface information, and existing conditions?
	• If yes:
	    ○ Exactly what information shall be included?
	    ○ When shall he include such information?
	    ○ Does the design-builder need to request such information or the owner shall provide it without needing the design-builder's request?
	    ○ If the design-builder's request is needed, how long does the owner have to respond?
	• If the owner does not provide sufficient site information, is the design-builder considered to have investigated the site and accepting the contract conditions based on this?
	• If hazardous material that is not mentioned in the contract documents is found on site:
	    ○ Which party shall bear the cost of testing the and removal of the hazardous material?
	    ○ Is the design-builder entitled to additional compensation and extension of time due to delays caused by such hazardous material?
	• When shall the owner furnish the site to the design-builder? (furnishing shall include issuing all relevant permits to enable the design-builder to fully use the site)
	• If substantially differing site conditions were encountered, is the design-builder entitled to a modification in the contract sum and the time for completion?

Personnel	• Is the owner's representative specified in the contract? • Does the contract specify that the owner's representative has the authority to act on behalf of the owner? • Does the design-builder have to send to the owner a list of the key personnel on site for the owner's approval prior to execution? • Does the owner have the right to request any changes in the design-builder's personnel? • If the owner is using a third party (engineer or project manager) to handle all communications and approvals with the design-builder, and he wants to change that third party in the middle of the project, does he have to take the design-builder's permission on the new third party prior to hiring them?

Site Work	• Which party is responsible for arranging and paying for the costs of the tests and inspections?
	• Are the tests and inspections required from the owner listed in the contract documents?
	• Which party bears the costs of additional tests that were not originally stated in the contract document?
	• Does the owner have the right to uncover covered work and perform tests on it?
	• If yes,
	    ○ Is the design-builder entitled for additional compensation and extension of time in case the tests showed that the revealed work is defective?
	    ○ Is the design-builder entitled for additional compensation and extension of time in case the tests showed that the revealed work is not defective?
	• When should the owner return the performance security (if any) to the design-builder?
	• Do site instructions need to be in writing?
	• Can the owner occupy the site or part of the site before the date of issuing the practical completion date?

Proof of Financial Security	• Must the owner furnish evidence that his financial arrangements are sufficient to make the payments to the design-builder?
	• If yes:
	    ○ Does the design-builder have to make such a request from the owner first?
	    ○ When does the owner provide this evidence?
	    ○ Does the owner have to inform the design-builder prior to making substantial changes to these financial arrangements?

Table 5.4. Continued. Checklist for Drafting "Other" Clauses Related to Owner's Obligations

Category	Questions Regarding Payment Provisions under Design-Build Projects

Timely Review of Submittals and Requests	• Does the design-builder furnish to the owner a schedule of submittals showing times for the expected submittals and the times needed for reviewing and processing each of them by the owner?
	• If yes:
	  o When does the design-builder furnish such schedule?
	  o Within how many days shall the owner approve the schedule of submittals after receiving them?
	• If no:
	  o How long does the owner have to review submittals and requests submitted by the design-builder?
	• What happens if the owner is late in replying to submittals and requests?
	• If the design-builder submits a claim for additional time or compensation, within how many days shall the owner respond?

Safety	• Which party is responsible for insuring health and safety of the people on site? • Does the owner, engineer, or design-builder set the safety standards? • If the owner becomes aware of safety hazards on site, does he have the right to: o Inform the design-builder about it, or • Interfere and fix the situation (in this case, who covers the added expenses and lost time?)
Insurance	• What are the different types of insurance required in the project? • What and who does each insurance type cover? • Which party is responsible for purchasing and maintaining each insurance? • When does each insurance expire? • Can the insurance be made partial for each part of the work?
Suspension and Termination	• Can the owner suspend the work? • If the owner wishes to suspend the work starting from a given day, when should he notify the design-builder of his intention to suspend? • How long can the owner suspend the work before the design-builder has the right to terminate the contract? • If work is suspended by the owner, what is the compensation deserved by the design-builder in this period? • Does the period of the suspension have to be written in the notice or the owner just has to notify the design-builder prior to the continuation of work? • What causes give the owner the right for a termination for cause? • Can the owner terminate the contract without cause? • What is the period that the owner should give the design-builder before terminating the contract? • If the design-builder took corrective actions after receiving the notice for termination, does the owner still have the right to terminate the contract for cause? • If yes, then what is the period at which the design-builder must take corrective actions to avoid termination for cause? • If work is terminated by the owner for cause, what is the compensation deserved by the design-builder? • If work is terminated by the owner without cause, what is the compensation deserved by the design-builder?

CHAPTER 6:
CONCLUSION

6.1 Research Summary and Conclusion

Due to the increasing risks and complexities of construction projects, as well as the differing views of the involved participants, construction claims and disputes are deemed unavoidable. When conflicts and claims are not settled using the means outlined in the contract, they turn into disputes; which have adverse impacts on cost, time, and relationships between parties. There is a consensus among practitioners and researchers that disputes are one of the main factors which prevent the successful completion of construction projects. Research streams in this area have been focused on developing dispute resolution mechanisms to minimize their impact when they take place, and on investigating means of preventing disputes from taking place from the beginning. As it turns out, preventing disputes from the beginning is always better than resolving them.

Factors that trigger disputes can take place at any project stage. For example, in the <u>*bidding stage*</u>, unrealistic bids trigger disputes. In the <u>*negotiations stage*</u>, lack of clarity and poor understanding of contractual clauses cause errors in administrating the contracts; which triggers disputes as well. In the <u>*construction stage*</u>, the occurrence of disruptions and the improper quantification of their impacts, as well as the unfitting mitigation strategies, trigger disputes. Despite the presence of several factors triggering disputes, we focus in this dissertation on bidding, out-of-sequence work, and contract administration due to the significant knowledge gaps that were found in their research streams. The identified <u>*knowledge gaps*</u> are as follows:

1. There is a lack of models that help contractors in estimating bid prices that maximize their probability of winning as well as expected profit; especially in cases of incomplete information or dynamic bidding behavior of their competitors (i.e. having bidding schemes that change significantly with time).

2. No works have been found that help parties in understanding the owner's obligations, the associated required procedures, and the interrelated repercussions for failure to such provisions in the different national and international forms of design-build contracts.

3. Despite the fact that out-of-sequence (OOS) work is one of the top factors that lead to productivity loss, the root causes of OOS work and their impacts have not been investigated in the literature. Moreover, no best practices have been established for OOS avoidance and mitigation.

4. Traditional scheduling and modeling techniques fail to grasp the full impacts of OOS work due to their limited ability to capture the highly dynamic nature of multiple feedback processes and interdependencies between project elements. Such dynamics of OOS work are poorly, if not, studied in the literature.

The ***goal*** of this research is to cover the previously mentioned knowledge gaps by providing various effective quantitative and qualitative means of construction dispute prevention and mitigation at the different project stages. The research has 4 objectives, one corresponding to each of the gaps. The following bullet points present the *objectives*, *how they were achieved*, and *how they will benefit the construction industry*:

1. *Objective 1: Develop an advanced model for construction bid price estimation that is able to draw sound statistical inferences even in cases of data incompleteness and dynamic behaviors of competitors*. This objective was achieved through creating novel mathematical formulations and heuristics that combine Bayesian statistics with decision theory. The Bayesian concepts enabled dealing with the uncertainties and dynamic behavior of competitors, and the decision-theoretic concepts allowed finding optimal bid price and probability of winning from the output of the Bayesian concepts. This should be beneficial to contractors as it will help them in developing stable bids that balance between the probability of winning and the expected profit. By doing so, contractors who are awarded projects will not attain claim-oriented behavior to recover losses resulting from bidding too low since their bid price is balanced. As such, this model will partake in creating a healthy contracting environment and preventing disputes arising from unbalanced bids. The model was used in two case studies and compared to three previous models in the literature to demonstrate its use and the effect of its different parameters.

2. *Objective 2: Present contract administration guidelines for utilizing owner's obligations clauses under the most widely used national and international standard forms of design-build contracts*. The objective was achieved through (a) analyzing provisions related to the owner's obligations in six national and international standard forms of contract; (b) performing a comparative analysis of such provisions among the studied contracts, and (c) developing guiding checklists containing the important considerations that should be included in the clauses related to the owner's obligations in any contract. The comparative analysis will enable parties to quickly review the owner's obligations in the different standard forms and help them in selecting the from that best fits their projects. Moreover, the developed checklists will guide parties in drafting the owner's obligations clauses in new contracts in a way that removes all ambiguities. This will promote efficient and effective contract administration, and partakes in minimizing disputes arising from poor contract administration.

3. *Objective 3: Identify the causes and early warning signs of OOS work and their characteristics, as well as the best practices to avoid and mitigate its impacts*. This objective is attained through holding extensive interviews with industry professionals, conducting detailed surveys, and developing and validating an OOS Decision Support Tool. The interviews and surveys led to the quantification of the likelihood of occurrence, relative impact, and risk rating of the factors triggering OOS work. They also enabled quantifying the impacts of OOS work on schedule, productivity, quality, cost, and safety. The developed OOS Decision Support Tool enables the stakeholders to analyze their projects in terms of their proneness to OOS work and provides them with tailored preemptive and reactive actions to prevent and mitigate OOS work in their projects. Such minimization of OOS work and mitigation of its impacts will reduce the relevant disputes and enhance the workflow of projects; thus, saving time and money. Moreover, this acts as the first comprehensive research that is focused solely on studying OOS work.

4. *Develop an advanced systematic model for analyzing the dynamics of OOS*. This objective is achieved through: (1) the use of SNA to demonstrate the shortage of current dynamic models studying OOS, and (2) the use of system dynamics to investigate and model the

different interconnected feedbacks related to OOS work in projects. The developed model grasps the rippled impacts of disruptions caused by OOS work. It also provides informative forensic analysis of the corresponding project overruns. A novel calibration heuristic was also developed to enable calibrating the model to any construction project and produce results that are tailored for that specific project. The developed model was calibrated to a real project; replicating its planned and actual behavior with minimal margin of error. What-if scenarios were performed, and conclusions were drawn. For example, it was shown that the not only the magnitude of OOS work impacts progress. The timing of OOS actually might have a larger impact than its magnitude on the project progress, depending on the project. Realizing this, project managers would decide on the different effort that is put to prevent OOS work at the different timings within the project. If used in construction projects following the provided procedure, the developed model could be of significant help in resolving disputes by analyzing the different OOS work of the different parties and determining the impacts caused by each party separately; thus, handling the blind spots of the traditional models that actually complicate the dispute resolution process. By enabling stakeholders to forecast the direct and indirect consequences of their policies, the model would aid them in making more informed decisions that will minimize the risk of disputes.

To this effect, it can be concluded that ***the developed bidding model, OOS Decision Support Tool, OOS dynamic analysis model, and contract administration guidelines effectively contribute to avoiding construction disputes at the different project stages with varying qualitative and quantitative capacities***. At the <u>bidding stage</u>, contractors could use the developed bidding model to produce optimal bid prices that balance between high probability of winning and high expected profit. By making this balance, contractors who win projects will have guaranteed some profits so they would not become claim-oriented to recover any losses resulting from overly low bids. At the <u>negotiations stage</u>, the presented contract administration guidelines would be used by the parties to make sure that they understand the provisions related to owner's obligations in their agreement. If the parties are drafting a new agreement, the guidelines would be of a substantial help. The newly drafted contract should be able to answer all 125 questions in the guidelines to be considered comprehensive and free of ambiguities related to owner's obligations. With a clearly drafted contract, and clear understanding of contract conditions -especially those related to payment, disputes are expected to significantly drop. Early at the <u>execution stage</u>, the parties would use the OOS Decision Support Tool to evaluate their project's proneness to OOS work based on their current managerial arrangements and compare such proneness to the industry average. The Tool would then present them with best practices to avoid OOS work and mitigate its impacts. Finally, the developed OOS analysis model utilizing SD could be used (1) in the <u>execution stage</u> to forecast the direct and indirect impacts of policy changes and OOS work for better decision-making, and (2) in the <u>closeout stage</u> to provide forensic analysis to disputes arising from disruption and its relevant rippled impacts that are grasped by traditional schedule analysis techniques.

6.2 Research Contribution

This research is distinctive from prior related research with respect to focus, purpose, and methods. One of the advantages of this research is that it is modular; it could be either taken as a whole, or each chapter could be considered a separate research on its own. Each chapter has its own distinct and noteworthy <u>intellectual merits</u> (contributions to the construction management body of knowledge) and <u>practical merits</u> (application to the industry). ***Collectively, all chapters share the overarching contribution of helping in avoiding construction disputes***. The following bullet points highlight the intellectual and industry merits of each of the chapters:

- **Chapter 2 – Decision-Theoretic Bidding Model in a Bayesian Framework**: The <u>*intellectual merits*</u> of this chapter lie in its novel integration of Bayesian statistics and decision theory in a way that has not been attempted before. The developed mathematical formulations grasp the uncertainties and stochastic variance of the competing bidders' past bids. They also enable incorporating the dynamic behavior of competitors and those with incomplete information about their bidding history without jeopardizing the statistical integrity of the inferences. As for the <u>*practical merits*</u>, the developed bidding model enables contractors to refine their bidding decisions; throughout increasing the probability of earning optimal profits whilst maximizing the probability of winning. Unlike other bidding models, the developed model produces optimal bid prices even in cases of incomplete information and dynamic behavior of competitors. We also provided detailed step-by step guidelines (summarized in the flowchart presented in Figure 2.5) to make it easy for the contractor to use the developed model.

- **Chapter 3 – Best Practices for Avoiding and Mitigating Out-of-Sequence (OOS) Work**: As for the *intellectual merits*, the chapter addresses a persistent missing piece in the construction management body of knowledge as it is the first research endeavor to investigate OOS work as a stand-alone project impactor. Eighty-eight causes of OOS work have been identified. For each of these causes, the likelihood of occurrence, relative impact on project, and risk rating are quantified; which has never been attempted before. Also, 54 early warning signs of OOS work were identified and rated based on their correlation to the occurrence of OOS work. Moreover, the impacts of OOS work on productivity, schedule, cost, quality, and safety have been quantified. Furthermore, the chapter provided comparison between owners and contractors to examine the difference in their perception of OOS work. This led to discovering some misalignments between both parties that were not addressed before. As for the *practical merits*, a user-friendly decision support tool has been developed to be used directly by practitioners. The tool presents the results of the research (of chapter 3) and enables the users to numerically evaluate their projects' proneness to the risks of OOS work compared to industry averages. Moreover, the tool presents practical and validated best practices that are tailored to the users' projects to avoid OOS work and mitigate its impacts. Such minimization of OOS work and mitigation of its impacts will reduce the relevant disputes and enhance the workflow of projects; thus, saving time and money. Furthermore, the comparison that was made between owners and contractors highlighted some differences that provide "heads-up" to promote alignment and enhanced communication between both parties for healthier project environments.

- **Chapter 4 – System Dynamics (SD) Modeling of Out-of-Sequence (OOS) Work**: As for the *intellectual merits*, since the goal of this research has not been attempted before, it is expected to contribute significantly to the construction management body of knowledge as it: 1) acts as the first research effort to address and model the dynamics of OOS work; 2) enhances the understanding of how OOS work directly and indirectly impacts productivity, quality, and cost; 3) enables the quantification of such impacts; 4) models

OOS work dynamically so that not only the magnitude of OOS but the timing of it as well impact the project; which mimics reality; 5) enables practitioners to perform different what-if scenarios to assess the effectiveness of their mitigation approaches and select the optimum one; 6) is modular in nature as mentioned earlier, so other researchers could build on it and expand its applicability, and 7) provides a multi-stage calibration methodology enabling practitioners to use it on almost any construction project and view results that are specifically tailored to such project for enhanced policy making. The model also contributes to the dynamic modeling body of knowledge. The logic behind the multi-stage calibration methodology could benefit dynamic modelers in complex models since most SD models utilize single-stage calibration that limits the capabilities of models. Moreover, the staffing module provides advanced concepts that have not been used in this fashion even in the dynamic modeling community; thus, it could be of benefit to dynamic modelers who are involved in project management and resource management research. As for the *practical merits*, the developed model could be of significant help in resolving disputes by analyzing the different OOS work of the different parties and determining the impacts caused by each party separately; thus, handling the blind spots of the traditional models that actually complicate the dispute resolution process. The model could be also used during the project for management and control. By enabling stakeholders to forecast the direct and indirect consequences of their policies, the model would aid them in making more informed decisions that will minimize the risk of disputes

- **Chapter 5 – Analysis of Owner's Obligations in Standard Forms of Design-Build Contracts**: Most of the contractual studies addressing the obligations of the parties are focused on design-bid-build contracts. Also, most of them are focused towards the contractor's obligations or dispute mitigation mechanisms. The *intellectual merits* of this chapter lie in its focus on administrating owner's obligations in design-build contracts; which is the first study of its kind and is the most comprehensive in its approach and associated analyses. The conducted analysis highlights the differences between the six major national and international standard forms of contract related to the owner's obligations. From such analysis, comprehensive unprecedented guidelines were developed to help stakeholders administer the clauses related to the owner's obligations. As for the *practical merits*, parties utilizing any of the major national and international contracts will be able to easily pinpoint the key owner's obligations in the studied contracts, the associated required procedures, and the interrelated repercussions for failure to such provisions. Moreover, the developed concise checklists are beneficial to stakeholders on two-fold: (1) the stakeholders can use the checklists to evaluate the strength of their contracts and their understanding of their contracts with respect to the provisions of owner's obligations – a stronger contract is a one that is able to answer more questions in the checklist, (2) the stakeholders can use the checklist as guidelines in drafting provisions related to owner's obligations in new contracts to make sure that such contracts are comprehensive and free of any ambiguities that might lead to disputes. As such, this will promote efficient and effective administration of construction contracts. As such, disputes resulting from lack of understanding or ambiguity of owner obligation clauses will be avoided; which will have a positive effect on construction projects.

6.3 Recommendations for Future Work

Each chapter concludes with its own set of recommendations for future work. This paragraph summarizes such recommendations. For the bidding model that is presented in chapter 2, in addition to the theoretical validation that is present, we propose validating the model from a practical view through using either large amounts real data sets of bids of several contractors competing against each other or through developing an agent-based model to simulate different contractors competing against each other. Each of the contractors would use a different bidding model, and the efficiency of the developed model would be compared to others in such simulation. For the OOS research in chapter 3, we recommend having projects using the developed OOS Decision Support Tool and map the outputted OOS Rating Score to the different project performance indicators. When this data is collected, regressions models could be developed to forecast the overruns of any project given its OOS Rating Score that is obtained from the project's managerial conditions. This will strengthen the applicability of the OOS Rating Score. For the system dynamics model in chapter 4, we present the recommendations for future direction in terms of guidelines for building a truly holistic model for project control and dispute analysis. The guidelines are in terms of which elements should be present in such model and how they are all interrelated to one another. Figure 4.23 demonstrates these guidelines in a conceptual framework that should be followed to accomplish such a holistic model. Finally, for chapter 5, we recommend continuing the stream of analyzing provisions of design-build contract and forming extensive guidelines in the rest of the topics other than the owner's obligations. Then, when such guidelines are complete, we recommend that legal experts use them to form a strong design-build standard form of contract that covers all the intended and non-intended shortcomings of the available standard forms of contract to further promote healthier contracting environment.

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APPENDICES

Appendix A:

Code and Source Files for The Bidding Case Studies

R Code of the First Case Study:

```
# CASE STUDY 1
# The CSV file has the markup for bidders 1, 2, and 3 for 30 bids.
# No need for MCMC because we have the markup directly. So no uncertainity.

# Installing packages and calling libraries
install.packages("MASS")
install.packages("fitdistrplus")
install.packages("logspline")
install.packages("lattice")

library(MASS)          # for the fitdistr function (but for this the user has to select the
distribution himself/herself)
library(fitdistrplus)  # for finding what distribution is best fit for my data
library(logspline)
library(lattice)       # for the qqmath function

# setting working directory to the same location as the CSV file
setwd("C:/Users/Ibrahim Abotaleb/Dropbox/UTK/PhD Classes/IE
608/Project/Case Studies/Case Study 1")
getwd()                # just to check

# Import data from CSV
case1data=read.csv("case1.csv")

# Extracting markup values of each bidder (Except for the last bid because it will be taken as the
observation [assumption])
B1markups=case1data[c(1:29),2]
B2markups=case1data[c(1:29),3]
B3markups=case1data[c(1:29),4]

# setting variables
# standard deviations (we will try 4 different SD. The default will be SD=1)
SD=c(1,2,3,4)
```

The distance from 0 to 10 is 101 (which is the number of columns in the matrices)`MarkupValues = seq(from=0, to=20, by=0.1)`

Probability of winning against bidder 1 (Each row for different SD)

```
Winning1 = matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Probability of winning against bidder 2 (Each row for different SD)

```
Winning2 = matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Probability of winning against bidder 3 (Each row for different SD)

```
Winning3 = matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Expected profit against bidder 1 (Each row for different SD)

```
ExpectedValue1 =
matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Expected profit against bidder 2 (Each row for different SD)

```
ExpectedValue2 =
matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Expected profit against bidder 3 (Each row for different SD)

```
ExpectedValue3 =
matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

```
BestMarkup1=c(0,0,0,0)        # Optimum markup of winning bidder 1
BestMarkup2=c(0,0,0,0)        # Optimum markup of winning bidder 2
BestMarkup3=c(0,0,0,0)        # Optimum markup of winning bidder 3
Prob1=c(0,0,0,0)        # Probability of winning bidder 1 corresponding to the optimum markup
Prob2=c(0,0,0,0)        # Probability of winning bidder 2 corresponding to the optimum markup
Prob3=c(0,0,0,0)        # Probability of winning bidder 3 corresponding to the optimum markup
MarkupFr=c(0,0,0,0)     # Optimum Markup (Friedman) for the 4 different SD
PWINFR=c(0,0,0,0)       # Corresponding Best Probability of Winning (Friedman) for the 4
different SD
MarkupGa=c(0,0,0,0)     # Optimum Markup (Gates) for the 4 different SD
PWINGA=c(0,0,0,0)       # Corresponding Best Probability of Winning (Gates) for the 4 different
SD
```

4 rows (row for each SD). Each row has data array of the expected profit (Friedman).

```
EXPECTEDPROFITFR=matrix(rep(0,length(MarkupValues)*length(SD)),length(
SD))
```

4 rows (row for each SD). Each row has data array of the expected profit (Friedman).

```
EXPECTEDPROFITGA=matrix(rep(0,length(MarkupValues)*length(SD)),length(
SD))
```

```
# Corresponding best probability of winning (Friedman)
PROBWINFR=matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
# Corresponding best probability of winning (Gates)
PROBWINGA=matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))

#################### Finding Best Fitting Prior Distribution ####################
################################ Bidder 1 ####################################
###########################################################################

# Finding the best-fitting distribution for our markup data
descdist(B1markups, discrete = FALSE)        # plotting the Cullen and Frey Graph
                                 # It showed that the weibull & normal distributions are the best fit
fitB1.weibull = fitdist(B1markups, "weibull")  # fitting data in weibull
fitB1.norm = fitdist(B1markups, "norm")       # fitting data in normal
plot(fitB1.norm)
plot(fitB1.weibull)
# so which is better?
fitB1.weibull$aic
fitB1.norm$aic
# seems like the weibull(scale=10.57, shape=2.15) is the best fit for bidder #1

# Kolmogorov-Smirnov Test to estimate whether my sample data is from the same distribution as my
assumed distribution
# If the p-value is > 0.05 I can assume that the sample data is drawn from the same distribution
ks.test(B1markups,"pweibull", scale = 10.5751266, shape =  2.1473805)

# Therefore, the prior function is:
Prior1 = function(x) {
  dweibull(x,scale=10.57, shape=2.15)
}

#################### Finding Best Fitting Prior Distribution ####################
################################ Bidder 2 ####################################
###########################################################################
```

```
# Finding the best-fitting distribution for our markup data
descdist(B2markups, discrete = FALSE)       # plotting the Cullen and Frey Graph
                                            # It showed that the uniform distribution is the best fit
fitB2.uniform = fitdist(B2markups, "unif")    # fitting data in uniform
fitB2.weibull = fitdist(B2markups, "weibull")  # fitting data in weibull (just for validation of the Cullen and Frey Graph)
fitB2.norm = fitdist(B2markups, "norm")       # fitting data in normal (just for validation of the Cullen and Frey Graph)
plot(fitB2.uniform)
plot(fitB2.norm)
plot(fitB2.weibull)
# so which is better?
fitB2.uniform$aic
fitB2.weibull$aic
fitB2.norm$aic
# seems like the uniform(min=0.4, max=19.4) is the best fit for bidder #2

# Kolmogorov-Smirnov Test to estimate whether my sample data is from the same distribution as my assumed distribution
# If the p-value is > 0.05 I can assume that the sample data is drawn from the same distribution
ks.test(B2markups,"punif", min=0.4, max=19.4)

# Therefore, the prior function is:
Prior2 = function(x) {
  dunif(x,min=0.4, max=19.4)
}

#################### Finding Best Fitting Prior Distribution ####################
############################### Bidder 3 ###################################
#########################################################################

# Finding the best-fitting distribution for our markup data
descdist(B3markups, discrete = FALSE)       # plotting the Cullen and Frey Graph
# It showed that the uniform distribution is the best fit
fitB3.uniform = fitdist(B3markups, "unif")        # fitting data in uniform
```

```
fitB3.weibull = fitdist(B3markups, "weibull")      # fitting data in weibull (just for validation of the Cullen and Frey Graph)
fitB3.norm = fitdist(B3markups, "norm")            # fitting data in normal (just for validation of the Cullen and Frey Graph)
plot(fitB3.uniform)
plot(fitB3.norm)
plot(fitB3.weibull)
# so which is better?
fitB3.uniform$aic
fitB3.weibull$aic
fitB3.norm$aic
# seems like the uniform(min=0.2, max=18.9) is the best fit for bidder #3

# Kolmogorov-Smirnov Test to estimate whether my sample data is from the same distribution as my assumed distribution
# If the p-value is > 0.05 I can assume that the sample data is drawn from the same distribution
ks.test(B3markups,"punif", min=0.2, max=18.9)
# the p-value is 0.47; which is ok, but it is not very satisfactory to the authors.
# It is better if we can find a distribution that results in a higher p-value so

# we used the logspline to fit the data becasue it has more than one peak
fit3=logspline(B3markups)
qqmath(B3markups, distribution = function(x) qlogspline(x,fit3), grid = TRUE)     # plot the Q-Q plot of the logspline fitting
qqmath(B3markups, distribution = function(x) qunif(x,min=0.2, max=18.9), grid = TRUE)  # copmare with the Q-Q plot of the uniform fitting
ks.test(B3markups,"plogspline", fit3)   # p-value is 0.99 which is way better than the 0.45 of the uniform

# Therefore, the prior function is:
Prior3 = function(x) {
  dlogspline(x,fit3)
}
#integrate the logspline to make sure that the area under the curve is equal to 1 (to qualify as a PDF)
integrate(Prior3,lower=0,upper=25)$value   # should be ~1
```

######################### Summary of the Prior Functions ##################################
###

We obtained these functions from the fitting (The upper part of this code)

```
Prior1 = function(x) {  dweibull(x,scale=10.57, shape=2.15) }
Prior2 = function(x) {  dunif(x,min=0.4, max=19.4) }
Prior3 = function(x) {  dlogspline(x,fit3) }

for (j in 1:length(SD))
{
```

########################## Defining the Likelihood Functions############################
###

The likelihood function for every bidder is the observation of the last bid; where such observation takes into consideration

the uncertainity of the relative cost estimations through formulating the likelihood function in a normal distribution with

the observation as the mean and the uncertainity as the standard deviation (we will use 4 different values for the SD)

```
Likelihood1 = function(x) {dnorm(x,case1data[30,2],SD[j])}
Likelihood2 = function(x) {dnorm(x,case1data[30,3],SD[j])}
Likelihood3 = function(x) {dnorm(x,case1data[30,4],SD[j])}
```

If we assume the last two bids form the likelihood

#Likelihood1 = function(x) {dnorm(x,case1data[30,2],SD[j])+dnorm(x,case1data[29,2],SD[j])}

#Likelihood2 = function(x) {dnorm(x,case1data[30,3],SD[j])+dnorm(x,case1data[29,3],SD[j])}

#Likelihood3 = function(x) {dnorm(x,case1data[30,4],SD[j])+dnorm(x,case1data[29,4],SD[j])}

######################## Defining the Posterior Functions ##################################
###

```
Posterior1 = function(x) {Prior1(x)*Likelihood1(x)}
Posterior2 = function(x) {Prior2(x)*Likelihood2(x)}
Posterior3 = function(x) {Prior3(x)*Likelihood3(x)}
```

################# Calculating the Probability of Winning and Expected Profit ################
######################### FOR EACH BIDDER SEPARATELY #########################
##

#------------------- Bidder 1----------------------#
#---#

```
# integration of the posterior function to get the probability of winning
NORM1=integrate(Posterior1,lower=0,upper=20)$value   # The normalizing factor
for (i in 1:length(MarkupValues)) {
  Winning1[j,i] =
integrate(Posterior1,lower=MarkupValues[i],upper=20)$value / NORM1
}
ExpectedValue1[j,] = MarkupValues*Winning1[j,]
## statistics
BestMarkup1[j]=MarkupValues[which(ExpectedValue1[j,]==max(ExpectedValu
e1[j,]))]
Prob1[j]=Winning1[j,which(MarkupValues==BestMarkup1[j])]
```

#------------------- Bidder 2------- --------------#
#---#

```
# integration of the posterior function to get the probability of winning
NORM2=integrate(Posterior2,lower=0,upper=20)$value   # The normalizing factor
for (i in 1:length(MarkupValues)) {
  Winning2[j,i] =
integrate(Posterior2,lower=MarkupValues[i],upper=20)$value / NORM2
}
ExpectedValue2[j,] = MarkupValues*Winning2[j,]
## statistics
BestMarkup2[j]=MarkupValues[which(ExpectedValue2[j,]==max(ExpectedValu
e2[j,]))]
Prob2[j]=Winning2[j,which(MarkupValues==BestMarkup2[j])]
```

#-------------------- Bidder 3 ----------------------#

#---#

```
# integration of the posterior function to get the probability of winning
NORM3=integrate(Posterior3,lower=0,upper=20)$value   # The normalizing factor
for (i in 1:length(MarkupValues)) {
  Winning3[j,i] =
integrate(Posterior3,lower=MarkupValues[i],upper=20)$value / NORM3
}
ExpectedValue3[j,] = MarkupValues*Winning3[j,]
## statistics
BestMarkup3[j]=MarkupValues[which(ExpectedValue3[j,]==max(ExpectedValu
e3[j,]))]
Prob3[j]=Winning3[j,which(MarkupValues==BestMarkup3[j])]


############### Calculating the Probability of Winning and Expected Profit ###############
###################### WINNING ALL (Friedman & Gates) ##########################
##############################################################################


# Using Friedman's Equation
PROBWINFR[j,]=Winning1[j,]*Winning2[j,]*Winning3[j,]
EXPECTEDPROFITFR[j,] = MarkupValues*PROBWINFR[j,]
MarkupFr[j]=MarkupValues[which(EXPECTEDPROFITFR[j,]==max(EXPECTEDPROFI
TFR[j,]))]
PWINFR[j]=PROBWINFR[j,which(MarkupValues==MarkupFr[j])]


# Using Gates' Equation
PROBWINGA[j,]=1/((1-Winning1[j,])/Winning1[j,] + (1-
Winning2[j,])/Winning2[j,] + (1-Winning3[j,])/Winning3[j,] + 1)
EXPECTEDPROFITGA[j,] = MarkupValues*PROBWINGA[j,]
MarkupGa[j]=MarkupValues[which(EXPECTEDPROFITGA[j,]==max(EXPECTEDPROFI
TGA[j,]))]
PWINGA[j]=PROBWINGA[j,which(MarkupValues==MarkupGa[j])]


############################################################################
```

PLOT 1

```
par(mar=c(4,4,4,4),mfrow=c(4,3))
```

Priors

```
curve(Prior1(x), from=0, to=20, main="Prior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Prior2(x), from=0, to=20, main="Prior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Prior3(x), from=0, to=20, main="Prior Distribution",
xlab="Markup %", ylab="Frequency")
```

Likelihoods

```
curve(Likelihood1(x), from=0, to=20, main="Likelihood function",
xlab="Markup %", ylab="Frequency")

curve(Likelihood2(x), from=0, to=20, main="Likelihood function",
xlab="Markup %", ylab="Frequency")

curve(Likelihood3(x), from=0, to=20, main="Likelihood function",
xlab="Markup %", ylab="Frequency")
```

Posterior

```
curve(Posterior1(x), from=0, to=20, main="Posterior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Posterior2(x), from=0, to=20, main="Posterior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Posterior3(x), from=0, to=20, main="Posterior Distribution",
xlab="Markup %", ylab="Frequency")
```

Expected Profit

```
plot(MarkupValues,ExpectedValue1[j,], main="Expected Profit",
xlab="Markup %", ylab="Expected Value", type="l", xlim=c(0,20))

abline(v = BestMarkup1[j], col="red" )

plot(MarkupValues,ExpectedValue2[j,], main="Expected Profit",
xlab="Markup %", ylab="Expected Value", type="l", xlim=c(0,20))

abline(v = BestMarkup2[j], col="red" )

plot(MarkupValues,ExpectedValue3[j,], main="Expected Profit",
xlab="Markup %", ylab="Expected Value", type="l", xlim=c(0,20))

abline(v = BestMarkup3[j], col="red" )
```

Winning probability

plot(MarkupValues,Winning1[j,], main="Competitor 1", xlab="Markup %", ylab="Probability of Winning", type="l")

plot(MarkupValues,Winning2[j,], main="Competitor 2", xlab="Markup %", ylab="Probability of Winning", type="l")

plot(MarkupValues,Winning3[j,], main="Competitor 3", xlab="Markup %", ylab="Probability of Winning", type="l")

```
} # ENF OF FOR
```

############################ Plotting the Results ############################

##################### WINNING ALL (Friedman & Gates) #####################

##

```
par(mar=c(4,4,4,4),mfrow=c(1,2))
```

EXPECTED PROFIT: Friedman and Gates at Different SD levels

Friedman

```
plot(MarkupValues,EXPECTEDPROFITFR[1,],
main=expression(paste("Expected Profit at Different ", sigma )),
xlab="Markup %", ylab="Expected Value", type="l", xlim=c(0,20),
col="black")
lines(MarkupValues,EXPECTEDPROFITFR[2,], type="l", lty=1, col="red")
lines(MarkupValues,EXPECTEDPROFITFR[3,], type="l", lty=1, col="blue")
lines(MarkupValues,EXPECTEDPROFITFR[4,], type="l", lty=1, col="green")
```

Gates

```
lines(MarkupValues,EXPECTEDPROFITGA[1,], type="l", lty=2, col="black")
lines(MarkupValues,EXPECTEDPROFITGA[2,], type="l", lty=2, col="red")
lines(MarkupValues,EXPECTEDPROFITGA[3,], type="l", lty=2, col="blue")
lines(MarkupValues,EXPECTEDPROFITGA[4,], type="l", lty=2, col="green")
```

Legend

```
legend(12, 0.95*max(EXPECTEDPROFITFR[1,]), c(expression(paste(sigma,"
= 1")),expression(paste(sigma," = 2")),expression(paste(sigma," =
3")),expression(paste(sigma," = 4"))), cex=0.8, lty=c(1,1),
col=c("black","red","blue","green"), bty="n")
legend(12, 0.6*max(EXPECTEDPROFITFR[1,]), c("Friedman","Gates"),
cex=0.8, lty=c(1,2), bty="n")
```

Probability of Winning: Friedman and Gates at Different SD levels

Friedman

```
plot(MarkupValues,PROBWINFR[1,], main=expression(paste("Probability of
Winning at Different ", sigma )), xlab="Markup %", ylab="Probability
of Winning %", type="l", xlim=c(0,20), ylim=c(0,1), col="black")

lines(MarkupValues,PROBWINFR[2,], type="l", lty=1, col="red")

lines(MarkupValues,PROBWINFR[3,], type="l", lty=1, col="blue")

lines(MarkupValues,PROBWINFR[4,], type="l", lty=1, col="green")

# Gates

lines(MarkupValues,PROBWINGA[1,], type="l", lty=2, col="black")

lines(MarkupValues,PROBWINGA[2,], type="l", lty=2, col="red")

lines(MarkupValues,PROBWINGA[3,], type="l", lty=2, col="blue")

lines(MarkupValues,PROBWINGA[4,], type="l", lty=2, col="green")

# Legend

legend(12, 0.9, c(expression(paste(sigma," =
1")),expression(paste(sigma," = 2")),expression(paste(sigma," =
3")),expression(paste(sigma," = 4"))), cex=0.8, lty=c(1,1),
col=c("black","red","blue","green"), bty="n")

legend(12, 0.6, c("Friedman","Gates"), cex=0.8, lty=c(1,2), bty="n")


######################## Plotting the sensitivity analysis #########################

t1=c(7.5,7.1,6.7,6.4)

t2=c(7.5,7.1,6.9,6.7)

t3=c(8.5,7.6,7.1,6.7)

t4=c(8.8,8.2,7.6,7.3)

t5=c(0.87,0.8,0.75,0.69)

t6=c(0.87,0.81,0.74,0.68)

t7=c(0.6,0.56,0.57,0.58)

t8=c(0.59,0.55,0.56,0.56)

par(mar=c(4,4,2,2),mfrow=c(1,4))

# Effect of sigma on optimum markup selection

plot(SD,t1,main="Scenario
1",type="p",xlab=expression(sigma),ylab="optimum markup %",lty=2,
pch=2,ylim=c(6,9),xaxp=c(1,4,3), cex.lab=1.3)


points(SD,t2,type="p",lty=3, pch=3)

legend(2.7, 9, c("Friedman","Gates"), cex=1.1, pch=c(2,3), bty="n")
```

```
plot(SD,t3,main="Scenario
2",type="p",xlab=expression(sigma),ylab="optimum markup %",lty=2,
pch=2, ylim=c(6,9),xaxp=c(1,4,3), cex.lab=1.3)


points(SD,t4,type="p",lty=3, pch=3)

legend(2.7, 9, c("Friedman","Gates"), cex=1.1, pch=c(2,3), bty="n")


plot(SD,t5,main="Scenario
1",type="p",xlab=expression(sigma),ylab="probability of
winning",lty=2, pch=2, ylim=c(0.5,0.9),xaxp=c(1,4,3), cex.lab=1.3)


points(SD,t6,type="p",lty=3, pch=3)

legend(2.7, 0.9, c("Friedman","Gates"), cex=1.1, pch=c(2,3), bty="n")


plot(SD,t7,main="Scenario
2",type="p",xlab=expression(sigma),ylab="probability of
winning",lty=2, pch=2, ylim=c(0.5,0.9),xaxp=c(1,4,3), cex.lab=1.3)


points(SD,t8,type="p",lty=3, pch=3)

legend(2.7, 0.9, c("Friedman","Gates"), cex=1.1, pch=c(2,3), bty="n")


################### Plotting Friedman and Gates Again (for paper) #####################

par(mar=c(4,4,2,2),mfrow=c(1,4))

## Expected Profit

# Friedman

plot(MarkupValues,EXPECTEDPROFITFR[1,], main="Friedman", xlab="Markup
%", ylab="Expected Value", type="l", xlim=c(0,20), cex.lab=1.3, lty=1)

lines(MarkupValues,EXPECTEDPROFITFR[2,], type="l", lty=2)

lines(MarkupValues,EXPECTEDPROFITFR[3,], type="l", lty=3)

lines(MarkupValues,EXPECTEDPROFITFR[4,], type="l", lty=4)

legend(9, 1*max(EXPECTEDPROFITFR[1,]), c(expression(paste(sigma," =
1%")),expression(paste(sigma," = 2%")),expression(paste(sigma," =
3%")),expression(paste(sigma," = 4%"))), cex=1.2, lty=c(1,2,3,4),
bty="n", adj=0.3)

grid(nx=NULL,ny=NULL,col = "lightgray")

# Gates

plot(MarkupValues,EXPECTEDPROFITGA[1,], main="Gates", xlab="Markup %",
ylab="Expected Value", type="l", xlim=c(0,20), cex.lab=1.3, lty=1)
```

```
lines(MarkupValues,EXPECTEDPROFITGA[2,], type="l", lty=2)

lines(MarkupValues,EXPECTEDPROFITGA[3,], type="l", lty=3)

lines(MarkupValues,EXPECTEDPROFITGA[4,], type="l", lty=4)

legend(9, 1*max(EXPECTEDPROFITGA[1,]), c(expression(paste(sigma," =
1%")),expression(paste(sigma," = 2%")),expression(paste(sigma," =
3%")),expression(paste(sigma," = 4%"))), cex=1.2, lty=c(1,2,3,4),
bty="n", adj=0.3)

grid(nx=NULL,ny=NULL,col = "lightgray")
```

Probability of winning

Friedman

```
plot(MarkupValues,PROBWINFR[1,], main="Friedman", xlab="Markup %",
ylab="Probability of Winning", type="l", xlim=c(0,20), cex.lab=1.3,
lty=1)

lines(MarkupValues,PROBWINFR[2,], type="l", lty=2)

lines(MarkupValues,PROBWINFR[3,], type="l", lty=3)

lines(MarkupValues,PROBWINFR[4,], type="l", lty=4)

legend(9, 1*max(PROBWINFR[1,]), c(expression(paste(sigma," =
1%")),expression(paste(sigma," = 2%")),expression(paste(sigma," =
3%")),expression(paste(sigma," = 4%"))), cex=1.2, lty=c(1,2,3,4),
bty="n", adj=0.3)

grid(nx=NULL,ny=NULL,col = "lightgray")
```

Gates

```
plot(MarkupValues,PROBWINGA[1,], main="Gates", xlab="Markup %",
ylab="Probability of Winning", type="l", xlim=c(0,20), cex.lab=1.3,
lty=1)

lines(MarkupValues,PROBWINGA[2,], type="l", lty=2)

lines(MarkupValues,PROBWINGA[3,], type="l", lty=3)

lines(MarkupValues,PROBWINGA[4,], type="l", lty=4)

legend(9, 1*max(PROBWINGA[1,]), c(expression(paste(sigma," =
1%")),expression(paste(sigma," = 2%")),expression(paste(sigma," =
3%")),expression(paste(sigma," = 4%"))), cex=1.2, lty=c(1,2,3,4),
bty="n", adj=0.3)

grid(nx=NULL,ny=NULL,col = "lightgray")
```

############################ Saving and Exporting Data ############################

##

```
datasummary=matrix(nrow=7,ncol=9)
```

```
datasummary[3,c(2:5)]=BestMarkup1
datasummary[4,c(2:5)]=BestMarkup2
datasummary[5,c(2:5)]=BestMarkup3
datasummary[3,c(6:9)]=Prob1
datasummary[4,c(6:9)]=Prob2
datasummary[5,c(6:9)]=Prob3
datasummary[6,c(2:5)]=MarkupFr
datasummary[6,c(6:9)]=PWINFR
datasummary[7,c(2:5)]=MarkupGa
datasummary[7,c(6:9)]=PWINGA
datasummary[1,c(2:5)]="Optimum Markup"
datasummary[1,c(6:9)]="Probability of Winning"
datasummary[2,c(2:9)]=
c("SD=2","SD=3","SD=4","SD=5","SD=2","SD=3","SD=4","SD=5")
datasummary[c(3:7),1]= c("Winning Bidder 1","Winning Bidder
2","Winning Bidder 3","Winning All (Friedman)","Winning All (Gates)")

write.csv(datasummary,file="case_1_summary.csv")

bookkeeping=matrix(nrow=20,ncol=2+length(MarkupValues))
bookkeeping[2,c(3:(length(MarkupValues)+2))]=MarkupValues
bookkeeping[2,2]="SD=2"
bookkeeping[3,c(3:(length(MarkupValues)+2))]=Winning1[1,]
bookkeeping[4,c(3:(length(MarkupValues)+2))]=Winning1[2,]
bookkeeping[5,c(3:(length(MarkupValues)+2))]=Winning1[3,]
bookkeeping[6,c(3:(length(MarkupValues)+2))]=ExpectedValue1[1,]
bookkeeping[2,c(3:(length(MarkupValues)+2))]=ExpectedValue1[2,]
bookkeeping[6,c(3:(length(MarkupValues)+2))]=ExpectedValue1[3,]
```

R Code of the Second Case Study

Case 2 Code

```
# CASE STUDY 2
# The CSV file has the markup for bidders  1(1), 2(55), 3(134), and 4(221) for various bids.
# We have 33 data points for bidder 1, 20 points for bidder 55, 12 points for bidder 134, and 6 points for bidder 221.



# Installing packages and calling libraries
install.packages("MASS")
install.packages("fitdistrplus")
install.packages("logspline")
install.packages("lattice")
install.packages("ADGofTest")
install.packages("kSamples")
install.packages("SuppDists")

library(MASS)         # for the fitdistr function (but for this I have to select the distribution myself)
library(fitdistrplus)    # for finding what distribution is best fit for my data
library(logspline)
library(lattice)        # for the qqmath function
library(ADGofTest)
library(SuppDists)
library(kSamples)

# setting working directory to the same location as the CSV file
setwd("C:/Users/Ibrahim Abotaleb/Dropbox/UTK/PhD Classes/IE 608/Project/Case Studies/Case Study 2")
getwd()   # just to check

# Import data from CSV
case2data=read.csv("case2.csv")
```

number of data points for each bidder
```
n1=length(case2data[,2])-sum(is.na(case2data[,2]))
n2=length(case2data[,3])-sum(is.na(case2data[,3]))
n3=length(case2data[,4])-sum(is.na(case2data[,4]))
n4=length(case2data[,5])-sum(is.na(case2data[,5]))
```

setting variables
```
sigma=2
nsim=10000
```
standard deviations (we will try 4 different SD. The default will be SD=1)
```
SD=c(2,3,4,5)
```

The distance from 0 to 10 is 101 (which is the number of columns in the matrices)
```
MarkupValues = seq(from=0, to=20, by=0.01)
```

Probability of winning against bidder 1 (Each row for different SD)
```
Winning1 = matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Probability of winning against bidder 2 (Each row for different SD)
```
Winning2 = matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Probability of winning against bidder 3 (Each row for different SD)
```
Winning3 = matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Probability of winning against bidder 4 (Each row for different SD)
```
Winning4 = matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Expected profit against bidder 1 (Each row for different SD)
```
ExpectedValue1 =
matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Expected profit against bidder 2 (Each row for different SD)
```
ExpectedValue2 =
matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Expected profit against bidder 3 (Each row for different SD)

```
ExpectedValue3 =
matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Expected profit against bidder 4 (Each row for different SD)

```
ExpectedValue4 =
matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

```
BestMarkup1=c(0,0,0,0)  # Optimum markup of winning bidder 1
BestMarkup2=c(0,0,0,0)  # Optimum markup of winning bidder 2
BestMarkup3=c(0,0,0,0)  # Optimum markup of winning bidder 3
BestMarkup4=c(0,0,0,0)  # Optimum markup of winning bidder 4
```

```
Prob1=c(0,0,0,0)     # Probability of winning bidder 1 corresponding to the optimum markup
Prob2=c(0,0,0,0)     # Probability of winning bidder 2 corresponding to the optimum markup
Prob3=c(0,0,0,0)     # Probability of winning bidder 3 corresponding to the optimum markup
Prob4=c(0,0,0,0)     # Probability of winning bidder 4 corresponding to the optimum markup
MarkupFr=c(0,0,0,0)  # Optimum Markup (Friedman) for the 4 different SD
PWINFR=c(0,0,0,0)    # Corresponding Best Probability of Winning (Friedman) for the 4 different
SD
MarkupGa=c(0,0,0,0)  # Optimum Markup (Gates) for the 4 different SD
PWINGA=c(0,0,0,0)    # Corresponding Best Probability of Winning (Gates) for the 4 different SD
```

4 rows (row for each SD). Each row has data array of the expected profit (Friedman).

```
EXPECTEDPROFITFR=matrix(rep(0,length(MarkupValues)*length(SD)),length(
SD))
```

4 rows (row for each SD). Each row has data array of the expected profit (Friedman).

```
EXPECTEDPROFITGA=matrix(rep(0,length(MarkupValues)*length(SD)),length(
SD))
```

Corresponding best probability of winning (Friedman)

```
PROBWINFR=matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

Corresponding best probability of winning (Gates)

```
PROBWINGA=matrix(rep(0,length(MarkupValues)*length(SD)),length(SD))
```

################ Forming preliminary priors using sigma and n-1 of observations ################
###
Forming preliminary prior distributions using sigma and n-1 of observations

function to be used in case of negative relative markup. We assume that there is no negative markup,
so we replace the values of any negative markup with a gamma distribution

Bidder 1
since bidder 1 has negative values of markup (which is out of the scope of the assumptions), we use gamma distribution
to represent its prior directly.

```
Prior1 = function(x) { dgamma(x,3,1.3) }
```

Bidder 2

```
preprior2 = function (x) {
  dnorm(x,case2data[1,3],sigma) + dnorm(x,case2data[3,3],sigma) + dnorm(x,case2data[6,3],sigma) + dnorm(x,case2data[8,3],sigma)
  + dnorm(x,case2data[9,3],sigma) + dnorm(x,case2data[13,3],sigma) + dnorm(x,case2data[14,3],sigma) + dnorm(x,case2data[15,3],sigma)
  + dnorm(x,case2data[18,3],sigma) + dnorm(x,case2data[19,3],sigma) + dnorm(x,case2data[20,3],sigma) + dnorm(x,case2data[17,3],sigma) + dgamma(x,3,2) + dgamma(x,3,2)
}
NORMP2=integrate(preprior2,lower=0,upper=20)$value

preprior2normalized= function (x) {preprior2(x)/NORMP2}    # This will be the target function in the MCMC sampling
```

Bidder 3

```
preprior3 = function (x) {
  dnorm(x,case2data[3,4],sigma) + dnorm(x,case2data[6,4],sigma) + dnorm(x,case2data[7,4],sigma) + dnorm(x,case2data[10,4],sigma) + dnorm(x,case2data[12,4],sigma) + dgamma(x,5,2) + dgamma(x,5,2)
}
```

```
NORMP3=integrate(preprior2,lower=0,upper=20)$value
preprior3normalized= function (x) {preprior3(x)/NORMP3}    # This will be the target function in the MCMC sampling


##### Bidder 4
preprior4 = function (x) {
  dnorm(x,case2data[1,5],sigma) + dnorm(x,case2data[2,5],sigma) + dnorm(x,case2data[3,5],sigma) + dnorm(x,case2data[4,5],sigma) + dnorm(x,case2data[5,5],sigma)
}


NORMP4=integrate(preprior2,lower=0,upper=20)$value
preprior4normalized= function (x) {preprior4(x)/NORMP4}   # This will be the target function in the MCMC sampling


##################### MCMC MH to sample from preliminary prior #####################
####################################################################################
# We will sample from using a random walk


######################### Bidder 1 #################################
# No need for MCMC, we already obtained its prior


######################### Bidder 2 #################################
X2=rep(0,nsim)     # initialize the chain
X2[1] = 1       # initial value
acceptance2=0
for (i in 2:nsim){
  Y2= X2[i-1]+rnorm(1,0,2) # candidate distribution - random walk
  if (Y2<0) {Y2= X2[i-1]+rnorm(1,0,2)} # Safety net
  if (Y2<0) {Y2= X2[i-1]+rnorm(1,0,2)} # Safety net
  rho2=preprior2normalized(Y2)/preprior2normalized(X2[i-1])  # calculating the probability of acceptance
  if (runif(1)<rho2){
    X2[i] = Y2
    acceptance2 = acceptance2 + 1
```

```
  }
  else{
    X2[i] = X2[i-1]
  }
}
acceptance2 = acceptance2 / nsim  # acceptance ratio

######################### Bidder 3 #################################
X3=rep(0,nsim)    # initialize the chain
X3[1] = 1             # initial value
acceptance3=0
for (i in 2:nsim){
  Y3= X3[i-1]+rnorm(1,0,2) # candidate distribution - random walk
  if (Y3<0) {Y3= X3[i-1]+rnorm(1,0,2)}  # Safety net
  if (Y3<0) {Y3= X3[i-1]+rnorm(1,0,2)} # Safety net
  rho3=preprior3normalized(Y3)/preprior3normalized(X3[i-1]) # calculating the probability of acceptance
  if (runif(1)<rho3){
    X3[i] = Y3
    acceptance3 = acceptance3 + 1
  }
  else{
    X3[i] = X3[i-1]
  }
}
acceptance3 = acceptance3 / nsim    # acceptance ratio

######################### Bidder 4 #################################
X4=rep(0,nsim)    # initialize the chain
X4[1] = 1      # initial value
acceptance4=0
for (i in 2:nsim){
  Y4= X4[i-1]+rnorm(1,0,2) # candidate distribution - random walk
  if (Y4<0) {Y4= X4[i-1]+rnorm(1,0,2)}  # Safety net
```

```
  if (Y4<0) {Y4= X4[i-1]+rnorm(1,0,2)} # Safety net
  rho4=preprior4normalized(Y4)/preprior4normalized(X4[i-1]) # calculating
the probability of acceptance
  if (runif(1)<rho4){
    X4[i] = Y4
    acceptance4 = acceptance4 + 1
  }
  else{
    X4[i] = X4[i-1]
  }
}
acceptance4 = acceptance4 / nsim  # acceptance ratio

###################### Summary of Sampled Points ###########################
# Burn in of the first 1000 values
B2markups=X2[501:nsim]
B3markups=X3[501:nsim]
B4markups=X4[501:nsim]

# Remove all zero values
B2markups = B2markups[B2markups>0]
B3markups = B3markups[B3markups>0]
B4markups = B4markups[B4markups>0]

##################### Finding Best Fitting Prior Distribution ###############
############################## Bidder 2 ###############################
#####################################################################

# Finding the best-fitting distribution for our markup data
descdist(B2markups, discrete = FALSE)        # plotting the Cullen and Frey Graph
                              # It showed that the uniform distribution is the best fit
fitB2.uniform = fitdist(B2markups, "unif")    # fitting data in uniform
fitB2.gamma = fitdist(B2markups, "gamma")    # fitting data in gamma
```

`fitB2.weibull = fitdist(B2markups, "weibull")` # fitting data in weibull (just for validation of the Cullen and Frey Graph)

`fitB2.norm = fitdist(B2markups, "norm")` # fitting data in normal (just for validation of the Cullen and Frey Graph)

```
plot(fitB2.uniform)
plot(fitB2.gamma)
plot(fitB2.weibull)
plot(fitB2.norm)
```

so which is better?

```
fitB2.uniform$aic
fitB2.gamma$aic
fitB2.weibull$aic
```
The best is Weibull (shape = 1.503327, scale = 4.222868)
```
fitB2.norm$aic
```

Kolmogorov-Smirnov Test to estimate whether my sample data is from the same distribution as my assumed distribution

If the p-value is > 0.05 I can assume that the sample data is drawn from the same distribution

```
ks.test(B2markups,"pnorm", mean=3.881263, sd=2.588148)
ks.test(B2markups,"pgamma", shape=1.8666929, rate=0.4809354)
ks.test(B2markups,"pweibull", shape=1.501228, scale=4.298098)
ad.test(B2markups,pweibull, shape=1.501228, scale=4.298098)
ad.test(B2markups,rweibull(length(B2markups),shape=1.501228, 
scale=4.298098))
```

Therefore, the prior function is:

```
Prior2 = function(x) {
  dweibull(x,shape = 1.503327, scale = 4.222868)
}
```

##################### Finding Best Fitting Prior Distribution ################

################################ Bidder 3 ################################

###

Finding the best-fitting distribution for our markup data

```
descdist(B3markups, discrete = FALSE)        # plotting the Cullen and Frey Graph
# It showed that the uniform distribution is the best fit
fitB3.uniform = fitdist(B3markups, "unif")     # fitting data in uniform
fitB3.weibull = fitdist(B3markups, "weibull")  # fitting data in weibull (just for validation of the Cullen and Frey Graph)
fitB3.norm = fitdist(B3markups, "norm")       # fitting data in normal (just for validation of the Cullen and Frey Graph)
plot(fitB3.uniform)
plot(fitB3.norm)
plot(fitB3.weibull)
# so which is better?
fitB3.uniform$aic
fitB3.weibull$aic
fitB3.norm$aic

# Not good enough for me. We want a better fit
# we used the logspline to fit the data becasue it has more than one peak
fit3=logspline(B3markups)
qqmath(B3markups, distribution = function(x) qlogspline(x,fit3), grid
= TRUE)     # plot the Q-Q plot of the logspline fitting
qqmath(B3markups, distribution = function(x) qweibull(x,shape=
1.418102, scale = 4.990609), grid = TRUE)  # copmare with the Q-Q plot
of the Weibul fitting
ks.test(B3markups,"plogspline", fit3)   # p-value is 0.99 which is way better than the 0.45 of the uniform

# Therefore, the prior function is:
Prior3 = function(x) {
  dlogspline(x,fit3)
}
#integrate the logspline to make sure that the area under the curve is equal to 1 (to qualify as a PDF)
integrate(Prior3,lower=0,upper=25)$value   # should be ~1

###################### Finding Best Fitting Prior Distribution ################
################################ Bidder 4 ################################
##############################################################################
```

```
# Finding the best-fitting distribution for our markup data
descdist(B4markups, discrete = FALSE)         # plotting the Cullen and Frey Graph
# It showed that the weibull & normal distributions are the best fit
fitB4.unif = fitdist(B4markups, "unif")  # fitting data in uniform
fitB4.weibull = fitdist(B4markups, "weibull")  # fitting data in weibull
fitB4.norm = fitdist(B4markups, "norm")      # fitting data in normal
fitB4.gamma = fitdist(B4markups, "gamma")      # fitting data in gamma
plot(fitB4.unif)
plot(fitB4.norm)
plot(fitB4.weibull)
plot(fitB4.gamma)
# parameters
fitB4.unif
fitB4.weibull
fitB4.norm
fitB4.gamma
# so which is better?
fitB4.weibull$aic
fitB4.gamma$aic
fitB4.norm$aic

# Kolmogorov-Smirnov Test to estimate whether my sample data is from the same distribution as my
assumed distribution
# If the p-value is > 0.05 We can assume that the sample data is drawn from the same distribution
ks.test(B1markups,"pweibull", scale = 10.5751266, shape =  2.1473805)

# Therefore, the prior function is:
Prior4 = function(x) {
  dweibull(x,shape=2.015762, scale=7.180601)
}

########################### Summary of the Prior Functions ###########################
#####################################################################################
```

```
# We obtained these functions from the fitting (The upper part of this code)
Prior1 = function(x) { dgamma(x,3,1.3) }
Prior2 = function(x) { dweibull(x,shape = 1.503327, scale = 4.222868)
}
Prior3 = function(x) { dlogspline(x,fit3) }
Prior4 = function(x) { dweibull(x,shape=2.015762, scale=7.180601) }



for (j in 1:length(SD))
{

######################## Defining the Likelihood Functions ########################
##################################################################################

# The likelihood function for every bidder is the observation of the last bid; where such observation takes into consideration
# the uncertainity of the relative cost estimations through formulating the likelihood function in a normal distribution with
# the observation as the mean and the uncertainity as the standard deviation (we will use 4 different values for the SD)
#Likelihood1 = function(x) {dnorm(x,2,SD[j])}              # assumption because it's negative
#Likelihood2 = function(x) {dnorm(x,case2data[20,3],SD[j])}
#Likelihood3 = function(x) {dnorm(x,case2data[12,4],SD[j])}
#Likelihood4 = function(x) {dnorm(x,2,SD[j])}              # assumption because it's negative

# Assuming last 2 observations for likelihood
Likelihood1 = function(x) {dnorm(x,2,SD[j])}                 # 
assumption because it's negative
Likelihood2 = function(x) 
{dnorm(x,case2data[20,3],SD[j])+dnorm(x,case2data[19,3],SD[j])}
Likelihood3 = function(x) 
{dnorm(x,case2data[12,4],SD[j])+dnorm(x,case2data[10,4],SD[j])}
Likelihood4 = function(x) 
{dnorm(x,2,SD[j])+dnorm(x,case2data[4,5],SD[j])}          # assumption because 
it's negative

########################## Defining the Posterior Functions ##########################
```

```
################################################################################

Posterior1 = function(x) {Prior1(x)*Likelihood1(x)}
Posterior2 = function(x) {Prior2(x)*Likelihood2(x)}
Posterior3 = function(x) {Prior3(x)*Likelihood3(x)}
Posterior4 = function(x) {Prior4(x)*Likelihood4(x)}

################## Calculating the Probability of Winning and Expected Profit ###############
######################### FOR EACH BIDDER SEPARATELY #########################
#################################################################################

#------------------- Bidder 1--------- -------------#
#---------------------------------------------------#

# integration of the posterior function to get the probability of winning
NORM1=integrate(Posterior1,lower=0,upper=20)$value       # The normalizing factor
for (i in 1:length(MarkupValues)) {
  Winning1[j,i] =
integrate(Posterior1,lower=MarkupValues[i],upper=20)$value / NORM1
}
ExpectedValue1[j,] = MarkupValues*Winning1[j,]
## statistics
BestMarkup1[j]=MarkupValues[which(ExpectedValue1[j,]==max(ExpectedValu
e1[j,]))]
Prob1[j]=Winning1[j,which(MarkupValues==BestMarkup1[j])]

#------------------- Bidder 2------- ---------------#
#---------------------------------------------------#

# integration of the posterior function to get the probability of winning
NORM2=integrate(Posterior2,lower=0,upper=20)$value   # The normalizing factor
for (i in 1:length(MarkupValues)) {
  Winning2[j,i] =
integrate(Posterior2,lower=MarkupValues[i],upper=20)$value / NORM2
}
```

```
ExpectedValue2[j,] = MarkupValues*Winning2[j,]
```

statistics

```
BestMarkup2[j]=MarkupValues[which(ExpectedValue2[j,]==max(ExpectedValu
e2[j,]))]
Prob2[j]=Winning2[j,which(MarkupValues==BestMarkup2[j])]
```

#------------------- Bidder 3 ---------------------#

#---#

integration of the posterior function to get the probability of winning

```
NORM3=integrate(Posterior3,lower=0,upper=20)$value  # The normalizing factor
for (i in 1:length(MarkupValues)) {
  Winning3[j,i] =
integrate(Posterior3,lower=MarkupValues[i],upper=20)$value / NORM3
}
ExpectedValue3[j,] = MarkupValues*Winning3[j,]
```

statistics

```
BestMarkup3[j]=MarkupValues[which(ExpectedValue3[j,]==max(ExpectedValu
e3[j,]))]
Prob3[j]=Winning3[j,which(MarkupValues==BestMarkup3[j])]
```

#------------------- Bidder 4---------------------#

#---#

integration of the posterior function to get the probability of winning

```
NORM4=integrate(Posterior4,lower=0,upper=20)$value   # The normalizing factor
for (i in 1:length(MarkupValues)) {
  Winning4[j,i] =
integrate(Posterior4,lower=MarkupValues[i],upper=20)$value / NORM4
}
ExpectedValue4[j,] = MarkupValues*Winning4[j,]
```

statistics

```
BestMarkup4[j]=MarkupValues[which(ExpectedValue4[j,]==max(ExpectedValu
e4[j,]))]
Prob4[j]=Winning4[j,which(MarkupValues==BestMarkup4[j])]
```

################## Calculating the Probability of Winning and Expected Profit #############
####################### WINNING ALL (Friedman & Gates) #######################
##

Using Friedman's Equation
winning all 4

```
PROBWINFR[j,]=Winning1[j,]*Winning2[j,]*Winning3[j,]*Winning4[j,]
# PROBWINFR[j,]=Winning1[j,]*Winning2[j,]*Winning3[j,]          # winning 1, 2, 3
# PROBWINFR[j,]=Winning1[j,]*Winning2[j,]                       # winning 1, 2
# PROBWINFR[j,]=Winning1[j,]*Winning3[j,]                       # winning 1, 3
# PROBWINFR[j,]=Winning2[j,]*Winning3[j,]                       # winning 2, 3
# PROBWINFR[j,]=Winning2[j,]*Winning4[j,]                       # winning 2, 4
EXPECTEDPROFITFR[j,] = MarkupValues*PROBWINFR[j,]
MarkupFr[j]=MarkupValues[which(EXPECTEDPROFITFR[j,]==max(EXPECTEDPROFI
TFR[j,]))]
PWINFR[j]=PROBWINFR[j,which(MarkupValues==MarkupFr[j])]
```

Using Gates' Equation

```
PROBWINGA[j,]=1/((1-Winning1[j,])/Winning1[j,] + (1-
Winning2[j,])/Winning2[j,] + (1-Winning3[j,])/Winning3[j,] +(1-
Winning4[j,])/Winning4[j,] + 1)
# PROBWINGA[j,]=1/((1-Winning1[j,])/Winning1[j,] + (1-Winning2[j,])/Winning2[j,] + (1-
Winning3[j,])/Winning3[j,] + 1)   # winning 1, 2, 3
# PROBWINGA[j,]=1/((1-Winning1[j,])/Winning1[j,] + (1-Winning2[j,])/Winning2[j,] + 1)
# winning 1, 2
# PROBWINGA[j,]=1/((1-Winning1[j,])/Winning1[j,] + (1-Winning3[j,])/Winning3[j,] + 1)
# winning 1, 3
# PROBWINGA[j,]=1/((1-Winning2[j,])/Winning2[j,] + (1-Winning3[j,])/Winning3[j,] + 1)
# winning 2, 3
# PROBWINGA[j,]=1/((1-Winning2[j,])/Winning2[j,] + (1-Winning4[j,])/Winning4[j,] + 1)
# winning 2, 4
EXPECTEDPROFITGA[j,] = MarkupValues*PROBWINGA[j,]
MarkupGa[j]=MarkupValues[which(EXPECTEDPROFITGA[j,]==max(EXPECTEDPROFI
TGA[j,]))]
PWINGA[j]=PROBWINGA[j,which(MarkupValues==MarkupGa[j])]
```

##

PLOT 1

```
par(mar=c(3,3,3,3),mfrow=c(3,4))
```

Priors

```
curve(Prior1(x), from=0, to=10, main="Prior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Prior2(x), from=0, to=10, main="Prior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Prior3(x), from=0, to=10, main="Prior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Prior4(x), from=0, to=10, main="Prior Distribution",
xlab="Markup %", ylab="Frequency")
```

Likelihoods

```
curve(Likelihood1(x), from=0, to=10, main="Likelihood function",
xlab="Markup %", ylab="Frequency")

curve(Likelihood2(x), from=0, to=10, main="Likelihood function",
xlab="Markup %", ylab="Frequency")

curve(Likelihood3(x), from=0, to=10, main="Likelihood function",
xlab="Markup %", ylab="Frequency")

curve(Likelihood4(x), from=0, to=10, main="Likelihood function",
xlab="Markup %", ylab="Frequency")
```

Posterior

```
curve(Posterior1(x), from=0, to=10, main="Posterior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Posterior2(x), from=0, to=10, main="Posterior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Posterior3(x), from=0, to=10, main="Posterior Distribution",
xlab="Markup %", ylab="Frequency")

curve(Posterior4(x), from=0, to=10, main="Posterior Distribution",
xlab="Markup %", ylab="Frequency")


} # ENF OF FOR
```

############################## Plotting the Results ##############################

###################### WINNING ALL (Friedman & Gates) ######################

##

```
par(mar=c(4,4,4,4),mfrow=c(1,2))
```

EXPECTED PROFIT: Friedman and Gates at Different SD levels

Friedman

```
plot(MarkupValues,EXPECTEDPROFITFR[1,],
main=expression(paste("Expected Profit at Different ", sigma )),
xlab="Markup %", ylab="Expected Value", type="l", xlim=c(0,10),
ylim=c(0,0.9), col="black")
```

```
lines(MarkupValues,EXPECTEDPROFITFR[2,], type="l", lty=1, col="red")
lines(MarkupValues,EXPECTEDPROFITFR[3,], type="l", lty=1, col="blue")
lines(MarkupValues,EXPECTEDPROFITFR[4,], type="l", lty=1, col="green")
```

Gates

```
lines(MarkupValues,EXPECTEDPROFITGA[1,], type="l", lty=2, col="black")
lines(MarkupValues,EXPECTEDPROFITGA[2,], type="l", lty=2, col="red")
lines(MarkupValues,EXPECTEDPROFITGA[3,], type="l", lty=2, col="blue")
lines(MarkupValues,EXPECTEDPROFITGA[4,], type="l", lty=2, col="green")
```

Legend

```
legend(6, 0.95*max(EXPECTEDPROFITFR[1,]), c(expression(paste(sigma," =
1")),expression(paste(sigma," = 2")),expression(paste(sigma," =
3")),expression(paste(sigma," = 4"))), cex=0.8, lty=c(1,1),
col=c("black","red","blue","green"), bty="n")
```

```
legend(6, 0.6*max(EXPECTEDPROFITFR[1,]), c("Friedman","Gates"),
cex=0.8, lty=c(1,2), bty="n")
```

Probability of Winning: Friedman and Gates at Different SD levels

Friedman

```
plot(MarkupValues,PROBWINFR[1,], main=expression(paste("Probability of
Winning at Different ", sigma )), xlab="Markup %", ylab="Probability
of Winning %", type="l", xlim=c(0,10), ylim=c(0,1), col="black")
```

```
lines(MarkupValues,PROBWINFR[2,], type="l", lty=1, col="red")
lines(MarkupValues,PROBWINFR[3,], type="l", lty=1, col="blue")
lines(MarkupValues,PROBWINFR[4,], type="l", lty=1, col="green")
```

Gates

```
lines(MarkupValues,PROBWINGA[1,], type="l", lty=2, col="black")
lines(MarkupValues,PROBWINGA[2,], type="l", lty=2, col="red")
lines(MarkupValues,PROBWINGA[3,], type="l", lty=2, col="blue")
lines(MarkupValues,PROBWINGA[4,], type="l", lty=2, col="green")
```

Legend

```
legend(6, 0.9, c(expression(paste(sigma," =
1")),expression(paste(sigma," = 2")),expression(paste(sigma," =
```

```
3")),expression(paste(sigma," = 4"))), cex=0.8, lty=c(1,1),
col=c("black","red","blue","green"), bty="n")

legend(6, 0.6, c("Friedman","Gates"), cex=0.8, lty=c(1,2), bty="n")
```

######################## Plotting the sensitivity analysis #########################

```
SSD=c(2,3,4)

t11=c(1.12,1.17,1.2)

t12=c(1.28,1.36,1.41)

t13=c(1.25,1.26,1.26)

t14=c(1.4,1.44,1.47)

t15=c(0.625,0.615,0.606)

t16=c(0.586,0.571,0.561)

t17=c(0.64,0.62,0.605)

t18=c(0.606,0.582,0.565)

par(mar=c(4,4,2,2),mfrow=c(1,4))
```

Effect of sigma on optimum markup selection

```
plot(SSD,t11,main="Scenario
1",type="p",xlab=expression(sigma),ylab="optimum markup %",lty=2,
pch=2,ylim=c(1,1.8),xaxp=c(2,4,2), cex.lab=1.3)

points(SSD,t12,type="p",lty=3, pch=3)

legend(3.2, 1.8, c("Friedman","Gates"), cex=1.1, pch=c(2,3), bty="n")

plot(SSD,t13,main="Scenario
2",type="p",xlab=expression(sigma),ylab="optimum markup %",lty=2,
pch=2, ylim=c(1,1.8),xaxp=c(2,4,2), cex.lab=1.3)

points(SSD,t14,type="p",lty=3, pch=3)

legend(3.2, 1.8, c("Friedman","Gates"), cex=1.1, pch=c(2,3), bty="n")

plot(SSD,t15,main="Scenario
1",type="p",xlab=expression(sigma),ylab="probability of
winning",lty=2, pch=2, ylim=c(0.5,0.9),xaxp=c(2,4,2), cex.lab=1.3)

points(SSD,t16,type="p",lty=3, pch=3)

legend(3.2, 0.9, c("Friedman","Gates"), cex=1.1, pch=c(2,3), bty="n")

plot(SSD,t17,main="Scenario
2",type="p",xlab=expression(sigma),ylab="probability of
winning",lty=2, pch=2, ylim=c(0.5,0.9),xaxp=c(2,4,2), cex.lab=1.3)

points(SSD,t18,type="p",lty=3, pch=3)

legend(3.2, 0.9, c("Friedman","Gates"), cex=1.1, pch=c(2,3), bty="n")
```

################## Plotting Friedman and Gates Again (for paper) ######################

```
par(mar=c(4,4,2,2),mfrow=c(1,4))
```

Expected Profit

Friedman

```
plot(MarkupValues,EXPECTEDPROFITFR[1,], main="Friedman", xlab="Markup %", ylab="Expected Value", type="l", xlim=c(0,8), cex.lab=1.3, lty=1)

lines(MarkupValues,EXPECTEDPROFITFR[2,], type="l", lty=2)

lines(MarkupValues,EXPECTEDPROFITFR[3,], type="l", lty=3)

lines(MarkupValues,EXPECTEDPROFITFR[4,], type="l", lty=4)

grid(nx=NULL,ny=NULL,col = "lightgray")

legend(3, 1*max(EXPECTEDPROFITFR[1,]), c(expression(paste(sigma," = 1%")),expression(paste(sigma," = 2%")),expression(paste(sigma," = 3%")),expression(paste(sigma," = 4%"))), cex=1.2, lty=c(1,2,3,4), bty="n", adj=0.3)
```

Gates

```
plot(MarkupValues,EXPECTEDPROFITGA[1,], main="Gates", xlab="Markup %", ylab="Expected Value", type="l", xlim=c(0,8), cex.lab=1.3, lty=1)

lines(MarkupValues,EXPECTEDPROFITGA[2,], type="l", lty=2)

lines(MarkupValues,EXPECTEDPROFITGA[3,], type="l", lty=3)

lines(MarkupValues,EXPECTEDPROFITGA[4,], type="l", lty=4)

grid(nx=NULL,ny=NULL,col = "lightgray")

legend(3, 1*max(EXPECTEDPROFITGA[1,]), c(expression(paste(sigma," = 1%")),expression(paste(sigma," = 2%")),expression(paste(sigma," = 3%")),expression(paste(sigma," = 4%"))), cex=1.2, lty=c(1,2,3,4), bty="n", adj=0.3)
```

Probability of winning

Friedman

```
plot(MarkupValues,PROBWINFR[1,], main="Friedman", xlab="Markup %", ylab="Probability of Winning", type="l", xlim=c(0,8), cex.lab=1.3, lty=1)

lines(MarkupValues,PROBWINFR[2,], type="l", lty=2)

lines(MarkupValues,PROBWINFR[3,], type="l", lty=3)

lines(MarkupValues,PROBWINFR[4,], type="l", lty=4)

grid(nx=NULL,ny=NULL,col = "lightgray")

legend(3, 1*max(PROBWINFR[1,]), c(expression(paste(sigma," = 1%")),expression(paste(sigma," = 2%")),expression(paste(sigma," = 3%")),expression(paste(sigma," = 4%"))), cex=1.2, lty=c(1,2,3,4), bty="n", adj=0.3)
```

Gates

```
plot(MarkupValues,PROBWINGA[1,], main="Gates", xlab="Markup %",
ylab="Probability of Winning", type="l", xlim=c(0,8), cex.lab=1.3,
lty=1)

lines(MarkupValues,PROBWINGA[2,], type="l", lty=2)

lines(MarkupValues,PROBWINGA[3,], type="l", lty=3)

lines(MarkupValues,PROBWINGA[4,], type="l", lty=4)

grid(nx=NULL,ny=NULL,col = "lightgray")

legend(3, 1*max(PROBWINGA[1,]), c(expression(paste(sigma," =
1%")),expression(paste(sigma," = 2%")),expression(paste(sigma," =
3%")),expression(paste(sigma," = 4%"))), cex=1.2, lty=c(1,2,3,4),
bty="n", adj=0.3)
```

########################### Saving and Exporting Data ###########################

###

```
datasummary=matrix(nrow=7,ncol=9)

datasummary[3,c(2:5)]=BestMarkup1

datasummary[4,c(2:5)]=BestMarkup2

datasummary[5,c(2:5)]=BestMarkup3

datasummary[3,c(6:9)]=Prob1

datasummary[4,c(6:9)]=Prob2

datasummary[5,c(6:9)]=Prob3

datasummary[6,c(2:5)]=MarkupFr

datasummary[6,c(6:9)]=PWINFR

datasummary[7,c(2:5)]=MarkupGa

datasummary[7,c(6:9)]=PWINGA

datasummary[1,c(2:5)]="Optimum Markup"

datasummary[1,c(6:9)]="Probability of Winning"

datasummary[2,c(2:9)]=
c("SD=2","SD=3","SD=4","SD=5","SD=2","SD=3","SD=4","SD=5")

datasummary[c(3:7),1]= c("Winning Bidder 1","Winning Bidder
2","Winning Bidder 3","Winning All (Friedman)","Winning All (Gates)")


write.csv(datasummary,file="case_2_summary.csv")
```

```
bookkeeping=matrix(nrow=20,ncol=2+length(MarkupValues))
bookkeeping[2,c(3:(length(MarkupValues)+2))]=MarkupValues
bookkeeping[2,2]="SD=2"
bookkeeping[3,c(3:(length(MarkupValues)+2))]=Winning1[1,]
bookkeeping[4,c(3:(length(MarkupValues)+2))]=Winning1[2,]
bookkeeping[5,c(3:(length(MarkupValues)+2))]=Winning1[3,]
bookkeeping[6,c(3:(length(MarkupValues)+2))]=ExpectedValue1[1,]
bookkeeping[2,c(3:(length(MarkupValues)+2))]=ExpectedValue1[2,]
bookkeeping[6,c(3:(length(MarkupValues)+2))]=ExpectedValue1[3,]
```

Bidders Information for the First Case Study

This table shows historical data of direct markup values of competitors. The data in the table is obtained from Christodoulou (2004).

Bid No	Bidder 1	Bidder 2	Bidder 3
1	15.3%	3.1%	10.0%
2	2.6%	17.0%	15.8%
3	5.0%	11.4%	12.1%
4	8.4%	5.3%	4.5%
5	11.9%	2.4%	14.5%
6	7.1%	1.4%	10.0%
7	2.9%	19.0%	9.5%
8	10.9%	16.4%	0.2%
9	18.6%	5.5%	1.7%
10	12.5%	9.5%	4.4%
11	13.7%	13.0%	4.3%
12	8.0%	13.3%	10.4%
13	13.9%	6.6%	2.2%
14	13.4%	11.0%	13.3%
15	5.1%	2.5%	18.7%
16	4.5%	18.6%	12.0%
17	18.9%	19.4%	1.8%
18	6.7%	13.7%	0.6%
19	8.3%	12.5%	18.0%
20	1.1%	8.1%	5.1%
21	8.9%	4.8%	11.7%
22	9.4%	10.0%	18.9%
23	11.4%	10.2%	9.7%
24	7.1%	7.2%	8.1%
25	9.5%	8.6%	10.6%
26	7.7%	2.6%	9.7%
27	11.2%	0.4%	1.3%
28	3.0%	3.0%	11.9%
29	15.1%	14.5%	4.8%
30	9.9%	15.5%	12.8%

Bidders Information for the Second Case Study

This table shows historical data of bid prices of competitors and own cost estimate of the firm performing the analysis. The data in the table is obtained from Skitmore and Pemberton (1994).

		Bid Price of Competitors				Difference in Markup between Firm and …			
Bid	**Cost Estimate**	**Bidder1**	**Bidder 55**	**Bidder 134**	**Bidder 221**	**Bidder 1**	**Bidder 55**	**Bidder 134**	**Bidder 221**
1	1,475,398	1,386,652	1,514,865	1,468,775		-6.02%	2.68%	-0.45%	
2	535,608	505,291				-5.66%			
3	1,366,863	1,271,146				-7.00%			
5	422,297	389,214	404,110			-7.83%	-4.31%		
6	2,161,120	2,058,210		2,116,877	2,198,655	-4.76%		-2.05%	1.74%
7	3,065,742	2,919,754	3,269,768	3,153,800		-4.76%	6.66%	2.87%	
8	7,351,929	7,035,339			7,935,257	-4.31%			7.93%
9	902,378				996,483				10.43 %
10	1,063,337	1,012,702				-4.76%			
11	1,947,733	1,811,845				-6.98%			
12	1,126,816	1,053,099				-6.54%			
13	698,005	652,341	666,545			-6.54%	-4.51%		
15	1,511,033		1,717,715				13.68%		
17	348,969			313,203				-10.25%	
18	483,862		447,021				-7.61%		
19	2,999,999	2,884,614	3,333,793	2,950,723		-3.85%	11.13%	-1.64%	
20	7,837,276	7,646,123	7,904,172	8,657,685		-2.44%	0.85%	10.47%	
21	3,854,074	3,705,840	3,971,051			-3.85%	3.04%		
22	615,015	580,203		597,730		-5.66%		-2.81%	
24	1,226,589	1,179,413				-3.85%			
25	2,762,123		2,685,127				-2.79%		
26	540,814	515,061	486,485			-4.76%	-10.05%		
27	1,876,612	1,770,389				-5.66%			
28	2,175,928	2,062,491			2,255,246	-5.21%			3.65%
29	608,957		559,596	619,065			-8.11%	1.66%	
30	2,639,525	2,538,005	2,861,665			-3.85%	8.42%		
32	559,351	530,190	608,242	546,641		-5.21%	8.74%	-2.27%	
33	853,793		847,621		792,966		-0.72%		-7.12%
35	871,927	830,407				-4.76%			
36	792,474	754,737				-4.76%			
37	7,279,854	7,067,819				-2.91%			
38	592,096	550,787				-6.98%			
40	2,205,359				2,332,476				5.76%
41	1,576,905	1,530,976				-2.91%			
42	3,732,133	3,641,105	3,866,339	3,922,937		-2.44%	3.60%	5.11%	
44	2,252,833	2,187,217	2,384,494			-2.91%	5.84%		
45	1,294,986		1,268,733	1,291,365			-2.03%	-0.28%	
46	2,857,275	2,787,585				-2.44%			
47	1,436,804	1,381,542	1,511,643			-3.85%	5.21%		
48	789,355	751,767	842,684	797,926		-4.76%	6.76%	1.09%	
50	386,983	351,803				-9.09%			
51	694,297	645,858				-6.98%			

Source File that is Used by the Code for the First Case Study

Source File Name: case1.csv

Bid No	Bidder 1	Bidder 2	Bidder 3
1	15.3	3.1	10
2	2.6	17	15.8
3	5	11.4	12.1
4	8.4	5.3	4.5
5	11.9	2.4	14.5
6	7.1	1.4	10
7	2.9	19	9.5
8	10.9	16.4	0.2
9	18.6	5.5	1.7
10	12.5	9.5	4.4
11	13.7	13	4.3
12	8	13.3	10.4
13	13.9	6.6	2.2
14	13.4	11	13.3
15	5.1	2.5	18.7
16	4.5	18.6	12
17	18.9	19.4	1.8
18	6.7	13.7	0.6
19	8.3	12.5	18
20	1.1	8.1	5.1
21	8.9	4.8	11.7
22	9.4	10	18.9
23	11.4	10.2	9.7
24	7.1	7.2	8.1
25	9.5	8.6	10.6
26	7.7	2.6	9.7
27	11.2	0.4	1.3
28	3	3	11.9
29	15.1	14.5	4.8
30	9.9	15.5	12.8

Source File that is Used by the Code for the Second Case Study

Source File Name: case2.csv

Bid No	Bidder 1	Bidder 55	Bidder 134	Bidder 221
1	-6.01505	2.675007	-0.4489	7.934353
2	-5.6603	-7.61395	-1.64253	10.42856
3	-7.00268	11.12647	10.46804	5.764005
4	-7.83406	-4.30668	-10.249	3.645249
5	-4.76188	-2.78757	-2.04723	1.736831
6	-4.76191	6.655028	2.872323	-7.12433
7	-4.30622	-8.10583	1.659887	
8	-4.7619	8.415908	-2.8105	
9	-6.97673	8.740666	-2.27228	
10	-6.54206	-0.72289	5.112465	
11	-6.54207	-10.0458	-0.27962	
12	-3.84617	-4.50713	1.085823	
13	-2.43902	13.67819		
14	-3.84616	3.59596		
15	-5.66035	5.844241		
16	-3.84611	-2.02728		
17	-4.7619	0.853562		
18	-5.66036	3.035152		
19	-5.21327	5.208713		
20	-3.84615	6.756022		
21	-5.21336			
22	-4.76187			
23	-4.76192			
24	-2.91263			
25	-6.97674			
26	-2.9126			
27	-2.43903			
28	-2.9126			
29	-2.43904			
30	-3.84618			
31	-4.76186			
32	-9.09084			
33	-6.9767			

Appendix B:

Questions Used in the Expert-Based Survey

Section 1. Respondent Data

Job Title: ____

City and State: ____

Personal Years of Experience in Construction: __________________________________

Category of the Company: *Check all that apply*

☐ Owner	☐ Consultant / Engineer	☐ General Contractor / Construction Manager	☐ Mechanical, Electrical, or Plumbing	☐ Supplier	☐ Other trade (specify):_______

Section 2. Out-of-sequence Work

1. How frequently do you typically encounter OOS in your projects?*

○ ○ ○ ○ ○

1 2 3 4 5

Rarely → Always

2. How would you rate the negative impacts of out-of-sequence (OOS) work in construction projects?**

○ ○ ○ ○ ○

A B C D E

Negligible → Extreme

3. Please fill the following table *(check all that apply to your personal experience)*:

Project types***	Rate the **frequency*** of OOS for the following project types					Rate the **impacts*** of OOS in the following project types				
	Rarely → Always					Negligible → Extreme				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
Industrial	O	O	O	O	O	O	O	O	O	O
Infrastructure	O	O	O	O	O	O	O	O	O	O
Building	O	O	O	O	O	O	O	O	O	O
Renovation/Revamp	O	O	O	O	O	O	O	O	O	O

<u>* Likelihood of Occurrence</u>
1 = Very low probability & occurs in only exceptional circumstances (<10% chance)
2 = Low chance and unlikely to occur in most circumstances (10%-35% chance)
3 = Medium chance and will occur in most circumstances (35%- 65% chance)
4 = High chance and will probably occur in most circumstances (65%-90% chance)
5 = Very high chance and almost certain and expected to occur (>90% chance)

<u> Relative Impact</u>**
A = Negligible and routine procedures sufficient to deal with the consequences (<5% increase in cost, or <5% increase in time)
B = Minor and would threaten an element of the function (5-10% increase in cost, or 5-10% increase in time)
C = Moderate and would necessitate significant adjustment to the overall function (10-20% increase in cost, or 10-20% increase in time)
D = Significant and would threaten goals and objectives (20-50% increase in cost, or 20-50% increase in time)
E = Extreme and would stop achievement of functional goals and objectives (>50% increase in cost, or >50% increase in time)

<u>*Project Types:</u>**
<u>Industrial Projects</u>
Capital projects that provides an output in terms of assemblies, sub-assemblies, chemical compounds, electricity, food, or other marketable goods. Industrial projects are primarily designed by chemical, mechanical, or electrical engineers, and may be considered "light" or "heavy" industrial based on the amount of process steps/equipment included in the project. Examples include the following:

- oil/gas production facilities
- textile mills
- chemical plants
- pharmaceutical plants
- paper mills
- steel/aluminum mills
- power plants
- manufacturing facilities
- food processing plants
- refineries
- civil/industrial infrastructure
- plant upgrade/retrofit

<u>Infrastructure Projects</u>
Capital project that provides transportation, distribution or facilities supporting commerce or interaction of goods, service, or people. Infrastructure projects generally impact multiple jurisdictions, stakeholder groups or a wide area. Examples include the following:

- airport runways
- electrical distribution/transmission
- pipelines/pumping stations
- flood control facilities
- highways
- dams or levees
- marine or air terminals
- navigation locks
- canals
- rails
- tunnels
- water/wastewater/solid waste processing
- telecommunication or other wide area networks.

<u>Building Projects</u>
Capital projects that provides an output in terms of space for living, working, or interacting. Building projects are primarily designed by architects and may be single or multiple stories in height. Examples include the following:
Offices

- Schools (classrooms)
- Banks
- Research and laboratory facilities
- Medical facilities
- Nursing homes
- Institutional buildings
- Stores and shopping centers
- Dormitories
- Apartments
- Hotels and motels
- Parking structures
- Warehouses
- Light assembly and manufacturing
- Churches
- Airport terminals
- Recreational and athletic facilities
- Public assembly and performance halls
- Industrial control buildings
- Government facilities

Renovation/Revamp Projects

or work of replacing, restoring, repairing, or improving this facility with capital funds or non-capital funds. It may include additional structures and systems to achieve a more functional, serviceable, or desirable condition, including improvement in the following respects:

- profitability
- reliability
- efficiency
- safety
- security
- environmental performance,
- or compliance with regulatory requirements

Aliases may include the following:

- retrofit
- reconstruction
- shutdown/turnaround/outage
- maintenance project(not including routine maintenance actions)
- modernization
- improvement project
- repair project(not including routine maintenance actions)
- alteration
- rehabilitation
- de-bottlenecking project
- refurbishment
- modification
- upgrade
- makeover
- rebuild
- overhaul
- replacement
- betterment
- reclamation
- regeneration
- redevelopment
- relocation
- reutilization
- restoration.

Section 3. Causes of Out-of-sequence Work

Causes of OOS: are the events that lead to out-of-sequence work; and thus negatively impacting project performance.

In the following tables, the left column shows possible causes of out-of-sequence work based on the following categories (each category has its own table):

A. Project Team
B. Planning / Scheduling
C. Engineering
D. Execution
E. Material Management
F. Quality Management
G. Safety Management
H. Resource Management
I. Change Management
J. Commissioning
K. Legal / Commercial Aspects

Please answer the following questions related the causes of OOS work.

A. Causes related to Project Team	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
A1. Lack of team alignment	O	O	O	O	O	O	O	O	O	O
A2. Leadership deficiency	O	O	O	O	O	O	O	O	O	O
A3. Project chain of command not properly established/followed	O	O	O	O	O	O	O	O	O	O
A4. Poor communication between different project parties throughout the project	O	O	O	O	O	O	O	O	O	O
A5. Inappropriate team size	O	O	O	O	O	O	O	O	O	O
A6. Not enough attention to periodical meetings	O	O	O	O	O	O	O	O	O	O
A7. Lack of project team experience relative to type and size of project	O	O	O	O	O	O	O	O	O	O
A8. Social and political influences within the project team	O	O	O	O	O	O	O	O	O	O
A9. Full project funds not available	O	O	O	O	O	O	O	O	O	O

B. Causes related to Planning / Scheduling	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
B1. Inadequate project baseline at the start of execution	O	O	O	O	O	O	O	O	O	O
B2. Lack of practical experience while planning	O	O	O	O	O	O	O	O	O	O
B3. Lack of consideration of stakeholder requirements in project planning	O	O	O	O	O	O	O	O	O	O
B4. Unrealistic activities duration	O	O	O	O	O	O	O	O	O	O
B5. Perceiving planning as fulfilling a requirement rather than value added	O	O	O	O	O	O	O	O	O	O
B6. Low clarity of scope while planning	O	O	O	O	O	O	O	O	O	O
B7. Uncertain labor productivity rates	O	O	O	O	O	O	O	O	O	O
B8. Late or no input from subcontractors for sequencing purposes	O	O	O	O	O	O	O	O	O	O
B9. Failure to identify schedule requirements for pre-commissioning	O	O	O	O	O	O	O	O	O	O
B10. Uncertain quantity identification for planning	O	O	O	O	O	O	O	O	O	O
B11. Inadequate project execution plan	O	O	O	O	O	O	O	O	O	O
B12. Excessive overlapping of scheduled activities	O	O	O	O	O	O	O	O	O	O

C. Causes related to Engineering	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
C1. Late design deliverables	O	O	O	O	O	O	O	O	O	O
C2. Slow response to RFIs	O	O	O	O	O	O	O	O	O	O
C3. Uncoordinated designs	O	O	O	O	O	O	O	O	O	O
C4. Errors or omissions	O	O	O	O	O	O	O	O	O	O
C5. Late vendor information	O	O	O	O	O	O	O	O	O	O
C6. Change in design	O	O	O	O	O	O	O	O	O	O
C7. Late change in specifications or material of construction	O	O	O	O	O	O	O	O	O	O
C8. Lack of constructability /operability /commissioning /startup input	O	O	O	O	O	O	O	O	O	O

D. Causes related to Execution	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
D1. Untimely mobilization	O	O	O	O	O	O	O	O	O	O
D2. Lack of consistent use of processes and procedures	O	O	O	O	O	O	O	O	O	O
D3. Poor management of subcontractor interfaces to address schedule updates	O	O	O	O	O	O	O	O	O	O
D4. Poor management of specifications and/or drawing revisions	O	O	O	O	O	O	O	O	O	O
D5. Later owner approval of contract deliverables	O	O	O	O	O	O	O	O	O	O
D6. Cash-flow restraints	O	O	O	O	O	O	O	O	O	O
D7. Expedited schedule to meet owner's requirements	O	O	O	O	O	O	O	O	O	O
D8. Engineer/architect errors or omissions in Issued for Construction (IFC) documentation	O	O	O	O	O	O	O	O	O	O
D9. Site congestion	O	O	O	O	O	O	O	O	O	O
D10. Inadequate coordination of site access	O	O	O	O	O	O	O	O	O	O
D11. Poor site-layout plan	O	O	O	O	O	O	O	O	O	O
D12. Quantity changes	O	O	O	O	O	O	O	O	O	O
D13. Late response to Requests for Information (RFIs)	O	O	O	O	O	O	O	O	O	O
D14. Excessive Requests for Information (RFIs) by contractors	O	O	O	O	O	O	O	O	O	O
D15. Late approval of submittals (example: shop drawings)	O	O	O	O	O	O	O	O	O	O
D16. Inadequate risk management	O	O	O	O	O	O	O	O	O	O
D17. Schedule pressure	O	O	O	O	O	O	O	O	O	O
D18. Achieving schedule milestones by partially completing work	O	O	O	O	O	O	O	O	O	O
D19. Funding pressure	O	O	O	O	O	O	O	O	O	O
D20. Poor schedule updating and monitoring	O	O	O	O	O	O	O	O	O	O
D21. Political instability / security issues	O	O	O	O	O	O	O	O	O	O

E. Causes related to Material Management	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
E1. Late or deficient owner-furnished items	O	O	O	O	O	O	O	O	O	O
E2. Poor procurement strategy	O	O	O	O	O	O	O	O	O	O
E3. Late delivery from vendors	O	O	O	O	O	O	O	O	O	O
E4. Inadequate expediting/material tracking system	O	O	O	O	O	O	O	O	O	O
E5. Insufficient or late vendor data	O	O	O	O	O	O	O	O	O	O
E6. Inadequate material storage	O	O	O	O	O	O	O	O	O	O
E7. Inadequate vertical transportation (cranes, elevators, etc.)	O	O	O	O	O	O	O	O	O	O
E8. Inadequate traffic and logistics	O	O	O	O	O	O	O	O	O	O

F. Causes related to Quality Management	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
F1. Inadequate inspection plans	O	O	O	O	O	O	O	O	O	O
F2. Inadequate site inspections (failure to abide by inspection plans)	O	O	O	O	O	O	O	O	O	O
F3. Inadequate fabrications / vendors inspections (offsite)	O	O	O	O	O	O	O	O	O	O
F4. Bypassing hold points	O	O	O	O	O	O	O	O	O	O
F5. Inadequate quality trending	O	O	O	O	O	O	O	O	O	O

G. Causes related to Safety Management	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
G1. Inadequate safety management practices	O	O	O	O	O	O	O	O	O	O
G2. Inadequate planning for required safety practices and site requirements	O	O	O	O	O	O	O	O	O	O
G3. Poor integration of safety considerations in design	O	O	O	O	O	O	O	O	O	O

H. Causes related to Resource Management	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
H1. Shortage of skilled labor	O	O	O	O	O	O	O	O	O	O
H2. Staff/craft turnover	O	O	O	O	O	O	O	O	O	O
H3. Later-than-planned personnel hiring approval by owner	O	O	O	O	O	O	O	O	O	O
H4. Inadequate resource leveling	O	O	O	O	O	O	O	O	O	O
H5. High percentage of absenteeism	O	O	O	O	O	O	O	O	O	O
H6. Crews having insufficient work to perform (piecemeal work)	O	O	O	O	O	O	O	O	O	O
H7. Craft labor agreement issues	O	O	O	O	O	O	O	O	O	O
H8. Stacking of trades	O	O	O	O	O	O	O	O	O	O

I. Causes related to Change Management	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
I1. Late scope changes requiring different/new equipment/processes	O	O	O	O	O	O	O	O	O	O
I2. Excessive field changes	O	O	O	O	O	O	O	O	O	O
I3. Lack of alignment of change order process	O	O	O	O	O	O	O	O	O	O
I4. Excessive directed changes	O	O	O	O	O	O	O	O	O	O
I5. Rejecting all change orders adding cost or schedule	O	O	O	O	O	O	O	O	O	O

J. Causes related to Commissioning	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
J1. Inadequate commissioning and startup plan	O	O	O	O	O	O	O	O	O	O
J2. Late engagement of commissioning group	O	O	O	O	O	O	O	O	O	O
J3. Changes of turnover schedule	O	O	O	O	O	O	O	O	O	O

K. Causes related to Legal/Commercial Aspects	Rate the **likelihood*** of occurrence of the following OOS causes (1: Rarely – 5: Always)					Rate the **impact**** of OOS as a result of the following causes (A: Negligible – E: Extreme)				
	1	**2**	**3**	**4**	**5**	**A**	**B**	**C**	**D**	**E**
K1. Lack of consistent contractual flow down to sub-tiers	O	O	O	O	O	O	O	O	O	O
K2. Location/social issues/neighbor interventions	O	O	O	O	O	O	O	O	O	O
K3. Restrictive / late permitting requirement (ex. environmental)	O	O	O	O	O	O	O	O	O	O
K4. Untimely contractual updates with regard to changes	O	O	O	O	O	O	O	O	O	O
K5. Delayed payments causing impacts to downstream trades	O	O	O	O	O	O	O	O	O	O
K6. Commercial incentive/penalty	O	O	O	O	O	O	O	O	O	O

* Likelihood of Occurrence
1 = Very low probability & occurs in only exceptional circumstances (<10% chance)
2 = Low chance and unlikely to occur in most circumstances (10%-35% chance)
3 = Medium chance and will occur in most circumstances (35%- 65% chance)
4 = High chance and will probably occur in most circumstances (65%-90% chance)
5 = Very high chance and almost certain and expected to occur (>90% chance)

** Relative Impact
A = Negligible and routine procedures sufficient to deal with the consequences (<5% increase in cost, or <5% increase in time)
B = Minor and would threaten an element of the function (5-10% increase in cost, or 5-10% increase in time)
C = Moderate and would necessitate significant adjustment to the overall function (10-20% increase in cost, or 10-20% increase in time)
D = Significant and would threaten goals and objectives (20-50% increase in cost, or 20-50% increase in time)
E = Extreme and would stop achievement of functional goals and objectives (>50% increase in cost, or >50% increase in time)

Section 4. Early Warning Signs of Out-of-sequence Work

Early warning signs: are events that are somehow correlated to, but do not necessarily directly cause, out-of-sequence work. In other words, when these events occur in a project, then you will have a feeling that OOS will probably take place.

How strongly are the following early warning signs correlated to OOS? (i.e. if any of these situations occurred, how strongly will you be worried that out-of-sequence work will take place later in the project?

A. Early Warning Signs Related to Project Team	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
A1. Poorly planned kickoff meeting.	O	O	O	O	O
A2. Inexperience in key roles.	O	O	O	O	O
A3. Changing operations personnel from design meetings to construction.	O	O	O	O	O

B. Early Warning Signs Related to Planning	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
B1. Multiple Issued for Construction (IFC) with holds releases during civil & structural work.	O	O	O	O	O
B2. Up and down quantity trends.	O	O	O	O	O
B3. Project weekly meeting is focused on numbers not information.	O	O	O	O	O
B4. Early usage of float in schedule.	O	O	O	O	O
B5. Initial schedule extending past clients wishes.	O	O	O	O	O
B6. Team members not providing important information about next week's work.	O	O	O	O	O
B7. Project team focused on showing good numbers rather than proactive actions.	O	O	O	O	O
B8. Planner coming with experience in different type of project	O	O	O	O	O

C. Early Warning Signs Related to Engineering	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
C1. Engineering risks taken by modifying their standard procedures and work processes.	O	O	O	O	O
C2. Increase in drawings revisions.	O	O	O	O	O
C3. Late Design specifications.	O	O	O	O	O
C4. Client issued specifications not meeting current codes.	O	O	O	O	O
C5. Continued discussions on specific process requirements	O	O	O	O	O
C6. Difficulty in getting systems input	O	O	O	O	O

D. Early Warning Signs Related to Execution	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
D1. Project decisions that do not support original plan.	O	O	O	O	O
D2. Construction team using outdated drawings, or drawings with holds.	O	O	O	O	O
D3. Weekly meetings focused on work assessment rather than discussing planned work or unplanned situations.	O	O	O	O	O
D4. Float usage early in schedule.	O	O	O	O	O
D5. High/growing percentage of critical activities in schedule.	O	O	O	O	O
D6. High number of open employee requisition	O	O	O	O	O
D7. Trending away from baseline progress curve					

E. Early Warning Signs Related to Material Management	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
E1. Late Purchase Orders (PO's)	O	O	O	O	O
E2. Fabrication holds	O	O	O	O	O
E3. Vendor data & inspections behind schedule	O	O	O	O	O

F. Early Warning Signs Related to Quality Management	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
F1. High percentage of rework.	O	O	O	O	O
F2. Inadequate quality management personnel	O	O	O	O	O
F3. High percentage of NCRs	O	O	O	O	O

G. Early Warning Signs Related to Safety Management	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
G1. Project decisions that do not support original plan of safe execution	O	O	O	O	O
G2. Adverse safety performance trends	O	O	O	O	O
G3. Shortage of safety professionals	O	O	O	O	O

H. Early Warning Signs Related to Resource Management	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
H1. Delayed placement of major equipment orders.	O	O	O	O	O
H2. Higher wages elsewhere	O	O	O	O	O
H3. Area recruiting increases.	O	O	O	O	O
H4. Exit interview – "leaving to work elsewhere".	O	O	O	O	O
H5. Increase in projects in the area.	O	O	O	O	O
H6. Trending away from baseline progress curve.	O	O	O	O	O
H7. Slow buildup of manpower loading curve.	O	O	O	O	O

I. Early Warning Signs Related to Change Management	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
I1. No client representative with project team.	O	O	O	O	O
I2. Changing operations personnel during model reviews.	O	O	O	O	O
I3. Late decisions on change	O	O	O	O	O
I4. High frequency of change	O	O	O	O	O

J. Early Warning Signs Related to Commissioning	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
J1. Late start of pre-commissioning activities.	O	O	O	O	O
J2. Lack of clear systems-based turnover processes.	O	O	O	O	O
J3. Inadequate transition planning from construction to commissioning	O	O	O	O	O

K. Early Warning Signs Related to Legal/Commercial Aspects	(1: least correlated - 5: most correlated)				
	1	**2**	**3**	**4**	**5**
K1. Neighborhood complaints upon mobilization.	O	O	O	O	O
K2. Different versions of drawings on site.	O	O	O	O	O
K3. Early coordination issues (starting at site mobilization).	O	O	O	O	O
K4. Inadequate status reports on permitting.	O	O	O	O	O
K5. Permit questions during detailed design.	O	O	O	O	O
K6. No clearly identified person to follow up on permits.	O	O	O	O	O
K7. Extra-ordinary emphasis on cash flow planning/management.	O	O	O	O	O

Section 5. Impacts of Out-of-sequence Work

1. Please rate how **severely** out-of-sequence construction work impacts the following project attributes (productivity, safety, quality, cost and schedule).

	Negligible → Extreme				
	A	**B**	**C**	**D**	**E**
Impacts of OOS					
• Productivity loss (input:output ratio)	O	O	O	O	O
• Safety risks (OSHA recordables, lost time injuries and fatalities)	O	O	O	O	O
• Quality decline (Punch-list items, rework, non-conformance, warranty)	O	O	O	O	O
• Cost overrun	O	O	O	O	O
• Schedule overrun (delays)	O	O	O	O	O

A = Negligible (<5% deviation from what is planned)
B = Minor (5-10% deviation from what is planned)
C = Moderate (10-20% deviation from what is planned)
D = Significant (20-50% deviation from what is planned)
E = Extreme (>50% deviation from what is planned)

Section 6. Preventive and Reactive Actions for Out-of-sequence Work

Preventive actions: are actions taken at the project initiation to minimize the probability of occurrence of out-of-sequence work from the first place.

Reactive actions: are actions taken as soon as the out-of-sequence work occurs in order to minimize its impacts.

In the following blank spaces, **please suggest** (1) preventive actions to prevent OOS from happening, and (2) reactive actions to minimize the negative impacts in the case of OOS occurrence.

(1) Preventive Actions:

(2) Reactive Actions:

Appendix C:

A User's Guide to the Out-Of-Sequence (OOS) Decision Support Tool

Introduction

The Out-of-Sequence (OOS) Decision Support Tool is a Microsoft Excel Macro-based software that consists of two different modules:

Module 1 - Summary Reports: This module presents the research findings with regards to the causes, early warning signs, and impacts of out-of-sequence (OOS) work. It also presents the overall recommended practices for preventing and mitigating OOS.

Module 2 - Mitigation Tool: This module calculates the OOS Rating score (which is a scoring system developed by the research team) of the project that the user is investigating. It also provides the detailed recommended practices for avoiding and mitigating the OOS work in that project depending on the conditions of that project.

Functions and Capabilities of the OOS Decision Support Tool

The OOS Decision Support Tool performs the following functions:

Capabilities	Module 1: Summary Reports	Module 2: Mitigation Tool
Present the 88 causes of OOS and their corresponding likelihood of occurrence, relative impact, and risk rating.	•	•
Present a comparison between owners and contractors with regards to the likelihood of occurrence and relative impact of the 88 causes of OOS.	•	•
Present the 54 early warning signs of OOS and their corresponding correlation with OOS.	•	
Present a comparison between owners and contractors with regards to the correlation rating of the OOS early warning signs.	•	
Present statistical correlations between the different causes, early warning signs, and recommended practices of OOS; and different project parameters.	•	
Present 21 recommended practices for preventing/mitigating OOS as well including information on actions, when to apply, conditions for successful application, targeted outcomes (supported with statistics), cautions, and illustrative examples.	•	
Calculate the OOS Rating Score for the user's project and compare it to the industry's average.		•
Determine the risk tier of the project.		•
Produce detailed recommended practices for preventing/mitigating OOS in the user's project based on the user's input and project stage.		•

When to Use the OOS Decision Support Tool?

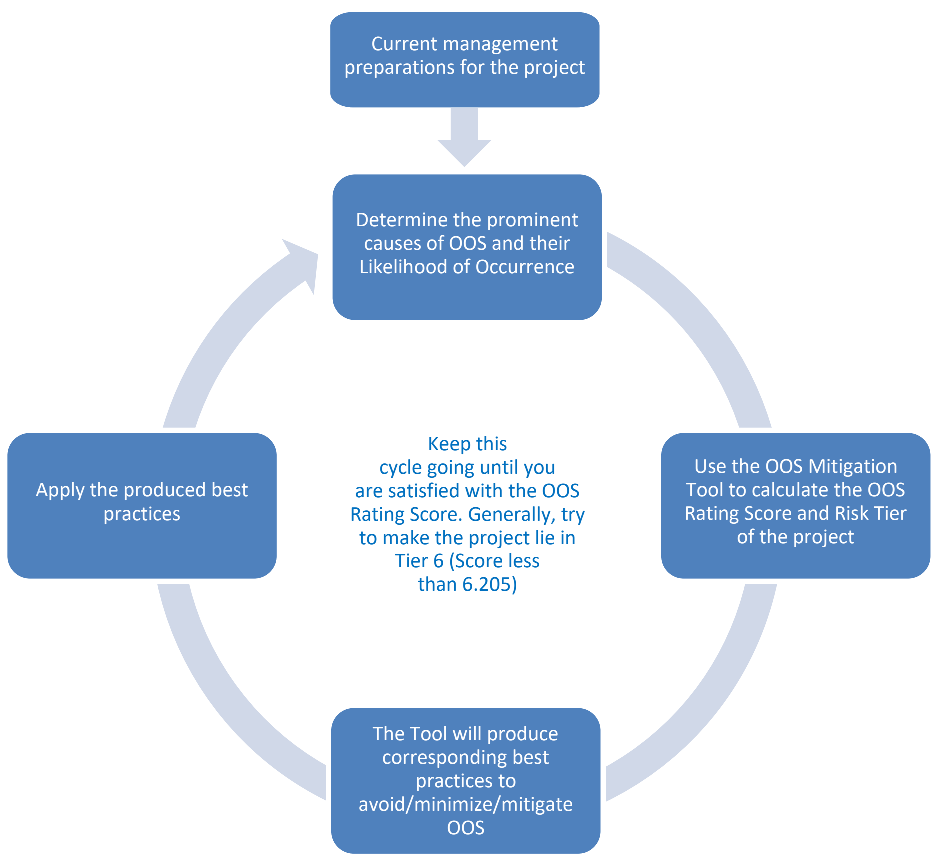
Answer: If you are involved in a construction project at the FEL2, FEL3, Design, or Construction phase and would like to:

- See the causes and early warning signs that lead to OOS, and/or
- Calculate the OOS Rating Score for your project and compare your project's OOS risk to the industry's score, and/or
- Know what actions to take (recommended practices) to avoid OOS (if you are at FEL2, FEL3, or Design) or mitigate OOS (if you are at the construction phase).

Or, if you just want to see summary reports on how OOS is manifested in the industry and the findings of the research team.

Getting the Maximum Benefit from the OOS Decision Support Tool

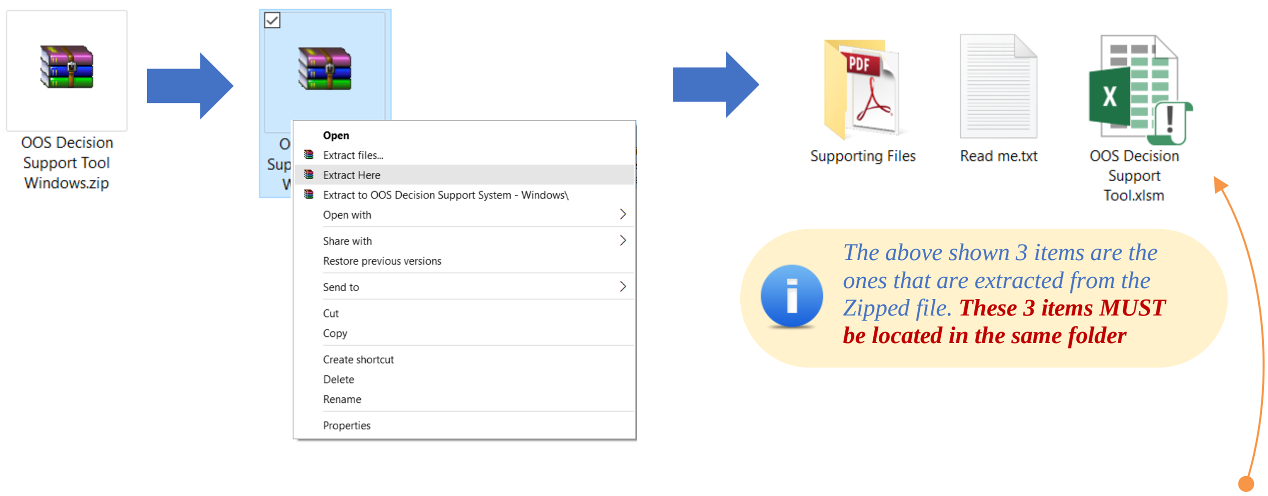
Users are encouraged to follow this sequence while using Module 2 - Mitigation Tool.



How to Initialize the OOS Decision Support Tool?

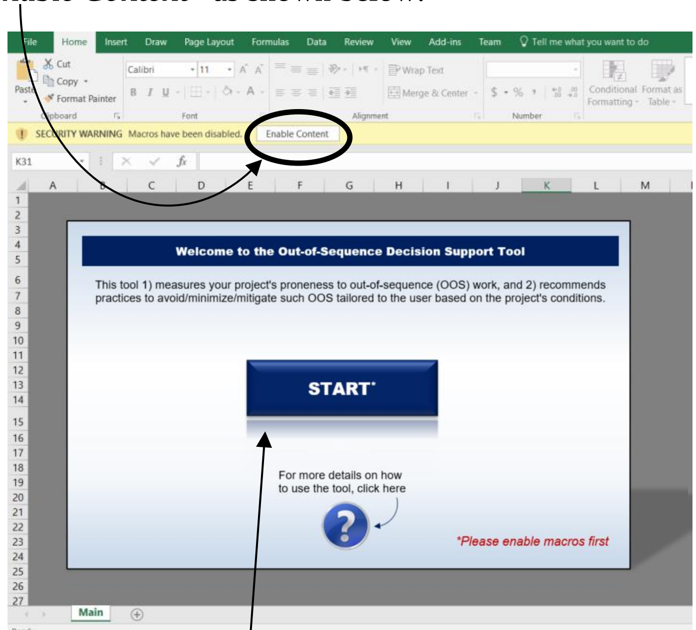
1. Download the OOS Decision Support Tool from the following link: https://goo.gl/dApxFL

2. After you download the compressed (zipped) file, extract (unzip) its contents to a single folder using Windows extraction capabilities or other software such as Winzip or WinRar as follows.



3. To start using the OOS Decision Support Tool, open the file named ***"[OOS Decision Support Tool.xlsm](#)"*** using Microsoft Excel (version 2010 or later).

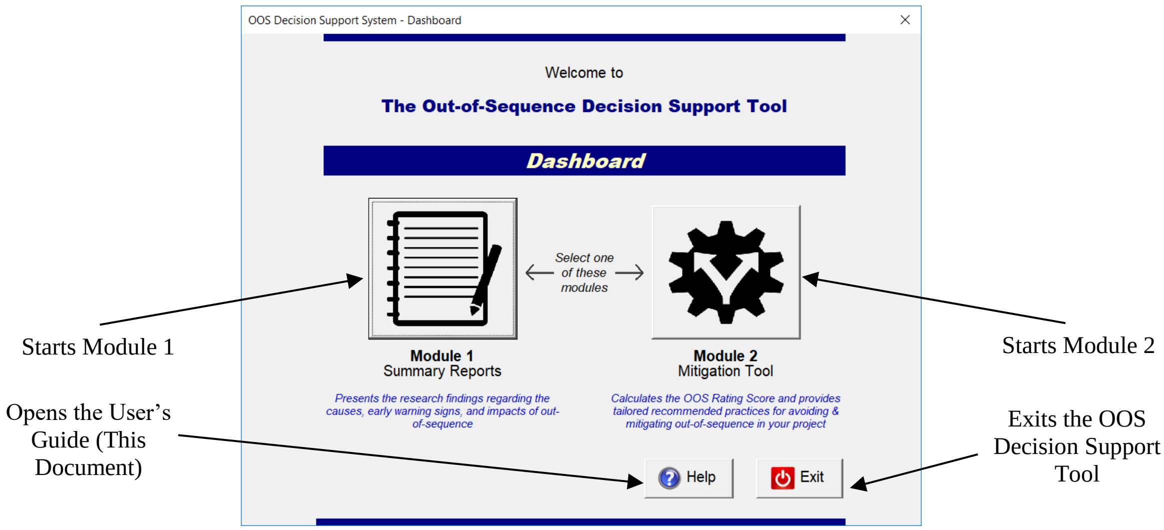
4. After you open the file, Microsoft Excel might warn you that Macros are disabled. If this happens, click **"*Enable Content*"** as shown below.



5. Start the Dashboard by clicking **"START"**.

How to Use the OOS Decision Support Tool?

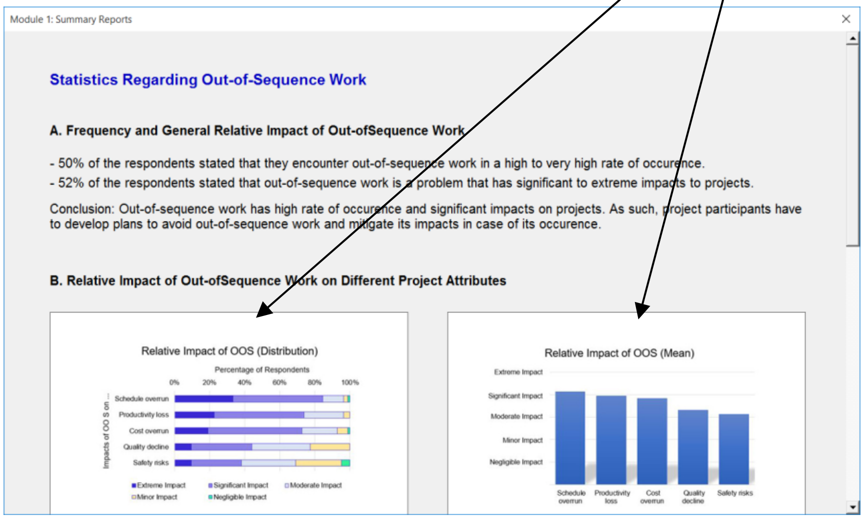
The OOS Decision Support Tool consists of many forms that are shown depending on the user's input. Each form requires certain inputs from the user. The first form is the **Dashboard**, which is the base point where the user can select which Module to use. The Dashboard form has 4 buttons as shown below.



The following sections explain how to use each of the modules.

Using Module 1 - Summary Reports

The top part of the form of Module 1 (shown below) presents some statistics regarding the rate of occurrence and impacts of OOS. If the user clicks on any of the two figures, the clicked figure magnifies so that it can be seen more clearly.

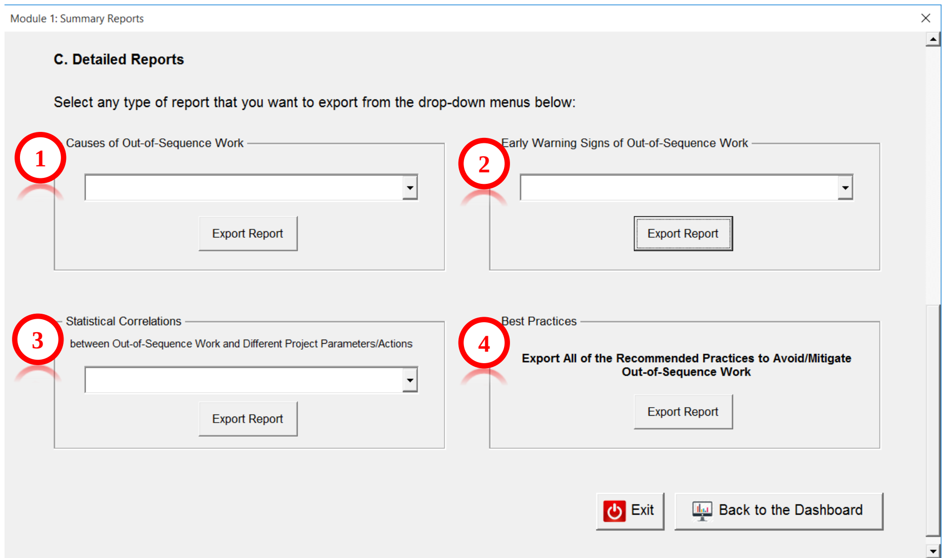


The form of Module 1, scrolled all the way up

The bottom part of the form of Module 1 (shown below) enables the user to export different reports regarding OOS. These reports are categorized under 4 groups:

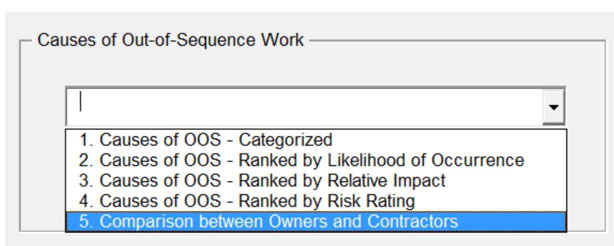
1. Causes of Out-of-Sequence (OOS) Work
2. Early Warning Signs of Out-of-Sequence (OOS) Work
3. Statistical Correlations
4. Best Practices

In each of the first three groups, there is a drop-down menu where the user chooses the type of report to be exported. The user selects the type of report and clicks the corresponding ***"Export Report"*** button to export the desired report.



The form of Module 1, scrolled all the way down

1 **In the <u>First Group (Causes of OOS Work)</u>, the following <u>reports</u> are available:**

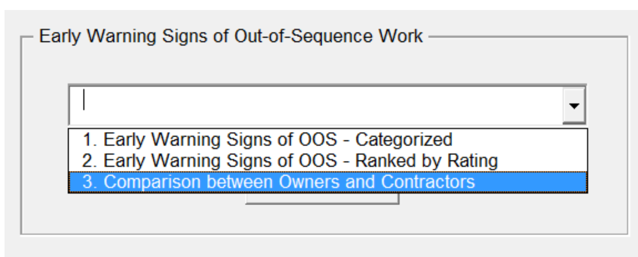


1. **Causes of OOS - Categorized:** Shows the 88 causes of OOS organized based on their categories (11 categories). The report shows the likelihood of occurrence, relative impact, risk rating, and risk tier for each of the OOS causes.
2. **Causes of OOS - Ranked by Likelihood of Occurrence:** Shows the 88 causes of OOS ranked based on their mean likelihood of occurrence. As such, users can spot those causes which occur more likely easily.

3. **Causes of OOS - Ranked by Relative Impact:** Shows the 88 causes of OOS ranked based on their mean relative impact. As such, users can spot those causes which have higher impacts on projects.
4. **Causes of OOS - Ranked by Risk Rating:** Shows the 88 causes of OOS ranked based on their risk rating. The risk rating is a measure that takes both the likelihood of occurrence and relative impact into consideration; thus acting as a measure of overall risk of these causes from an OOS point of view.
5. **Comparison between Owners and Contractors:** Shows a comparison between the owners' perception and the contractors' perception of likelihood of occurrence and relative impact of the different causes of OOS. It also shows where there are statistically significant differences between those perceptions; thus, highlighting points of lack of alignment.

The numbers and measures supplied in the reports of this group are the end-product of surveying 88 construction experts.

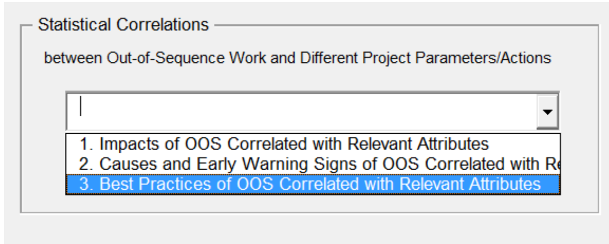
2 **In the <u>Second Group (Early Warning Signs of OOS Work)</u>, the following <u>reports</u> are available:**



1. **Early Warning Signs of OOS - Categorized:** Shows the 54 early warning signs of OOS organized based on their categories (11 categories). The report shows strength of correlation between those early warning signs and OOS.
2. **Early Warning Signs of OOS - Ranked by Rating:** Shows the 54 early warning signs of OOS ranked based on their mean rating (which is a measure of their correlation to OOS).
3. **Comparison between Owners and Contractors:** Shows a comparison between the owners' perception and the contractors' perception of the different early warning signs and their correlation to OOS.

The numbers and measures supplied in the reports of this group are the end-product of surveying 88 construction experts.

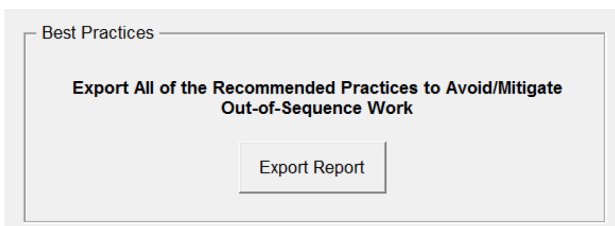
3 In the <u>Third Group (Statistical Correlations)</u>, the following <u>reports</u> are available:



1. **Impacts of OOS Correlated with Relevant Attributes:** Shows statistical correlations between OOS parameters (such as percent of activities performed OOS) and different project attributes (such as productivity index and schedule growth).
2. **Causes and Early Warning Signs of OOS Correlated with Relevant Attributes:** Shows statistical correlations between OOS parameters (such as percent of activities performed OOS) and different factors (such as the RFI process).
3. **Best Practices of OOS Correlated with Relevant Attributes:** Shows statistical correlations between OOS parameters (such as percent of activities performed OOS) and different best practices (such as front-end-planning).

The numbers and measures supplied in the reports of this group are the end-product of data obtained from 42 construction projects.

4 In the <u>Fourth Group (Recommended Practices)</u>, the following <u>report</u> is available:

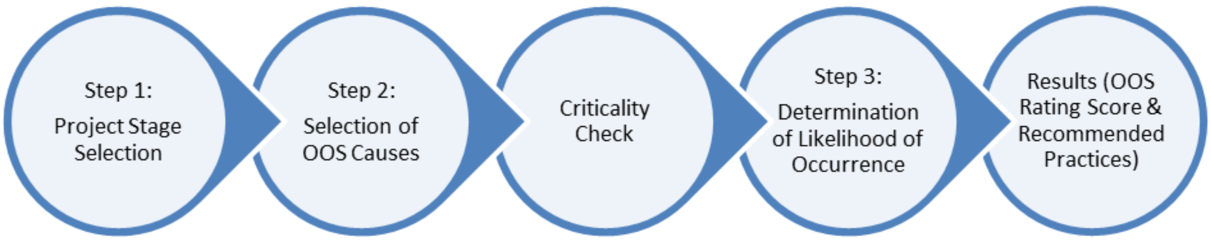


1. **Recommended Practices:** Shows 21 recommended practices for avoiding and mitigating OOS. It also shows information on actions, when to apply, conditions for successful application, targeted outcomes (supported with statistics), cautions, and illustrative examples. Moreover, it tells the user which practice corresponds to which causes of OOS and at which project stages should the different actions be taken.

These recommended practices are the end-product of surveying 88 experts, obtaining qualitative data from 42 projects, and working with the team's industry members.

Using Module 2 - Mitigation Tool

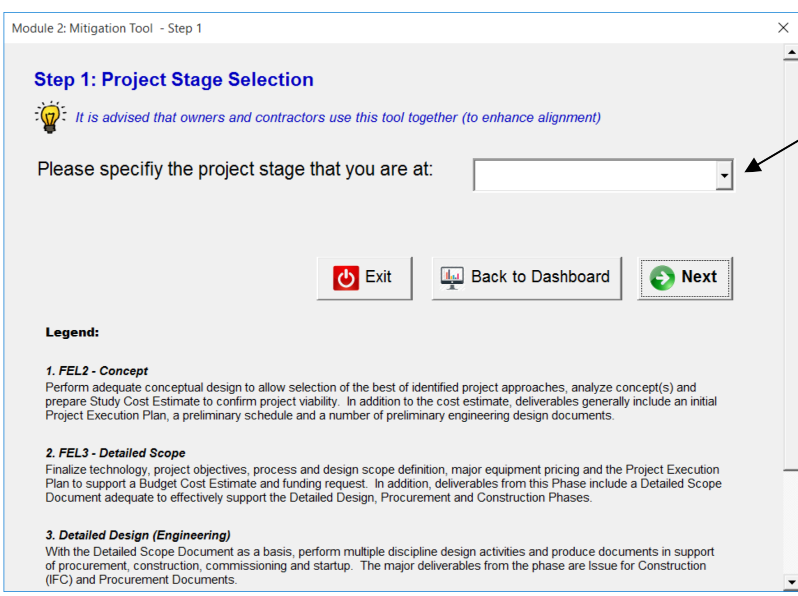
This module consists of the following sequential steps



Contractors and Owners of the same project are encouraged to use the Mitigation Tool together so that they are aligned when it comes to the inputs that the tool requires. It also grants that the calculated OOS Rating Score is representative and the developed recommended practices are of benefit.

Step 1: Project Stage Selection

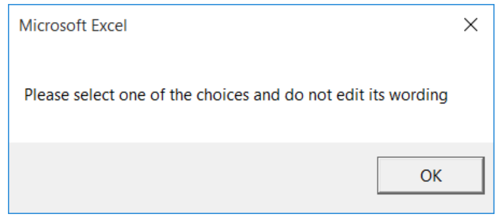
In this step, the user is asked to input the project stage that he/she is currently at as shown below. The form of this stage defines the different project stages to the user as well. The project stages are in concordance with the CII.



Drop-down menu for selecting the project stage

Available Project Stages:
- FEL2 - Concept
- FEL3 - Detailed Scope
- Detailed Design (Engineering)
- Construction

*If the user clicks **"Next"** without selecting a project stage from the drop-down menu, the tool will not proceed to the next step and the following warning message will appear.*



Step 2: Selection of OOS Causes

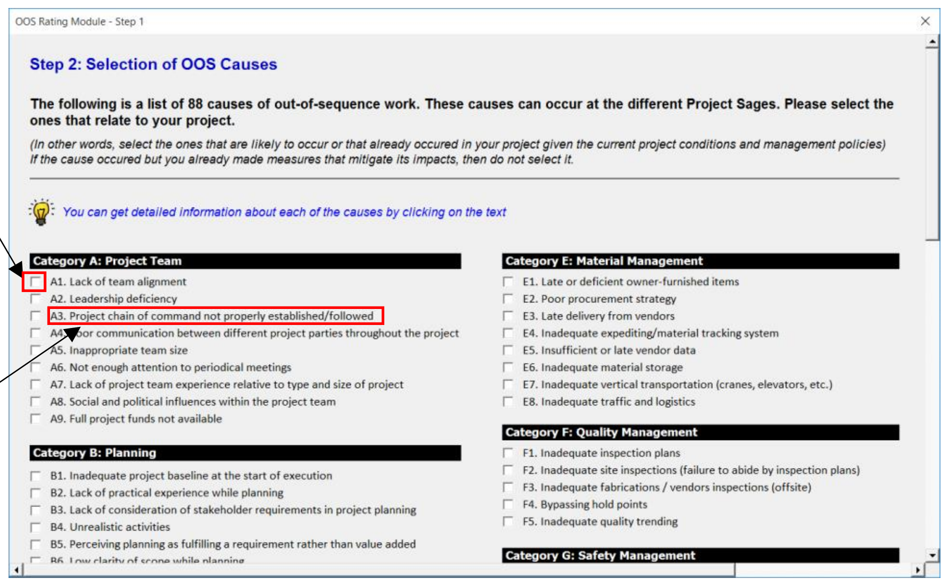
After clicking ***"Next"*** in Step 1, the form of Step 2 appears as shown below.

In this step, 88 causes of OOS are shown to user under the different 11 categories. The user is prompted to select the causes that are expected in his/her project by clicking on the checkboxes as shown below.

These checkboxes are where the user is supposed to click

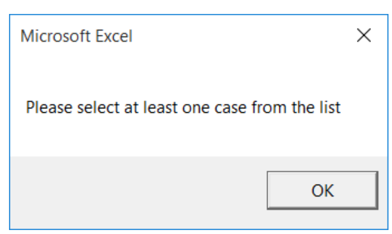
If the user hovers the mouse over the TEXT of any of the causes, the cursor will change to

By clicking on the TEXT of any cause, a one-page report will open showing more details about this cause



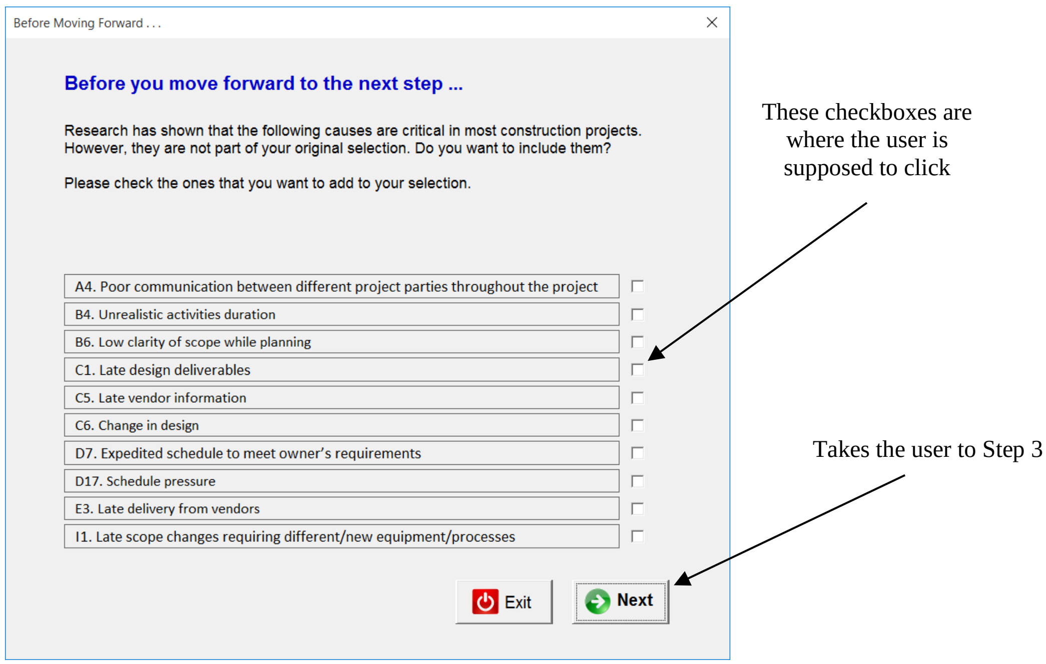
After selecting the causes, the user should click ***"Next"***.

*If the user clicks **"Next"** without selecting at least one cause of OOS, the tool will not proceed to the next step and the following warning message will appear.*



Criticality Check

The tool realizes the riskiest causes of OOS (the ones with the highest risk rating). If the causes selected by the user in Step 2 do not include all of the risky ones, this criticality check appears showing the risky causes that are not selected by the user as shown below. The user has the freedom to select any of these risky causes or leave them unselected.



However, if the causes selected by the user in Step 2 include all risky causes, this criticality check will not appear and the tool will proceed to Step 3.

Step 3: Determination of Likelihood of Occurrence

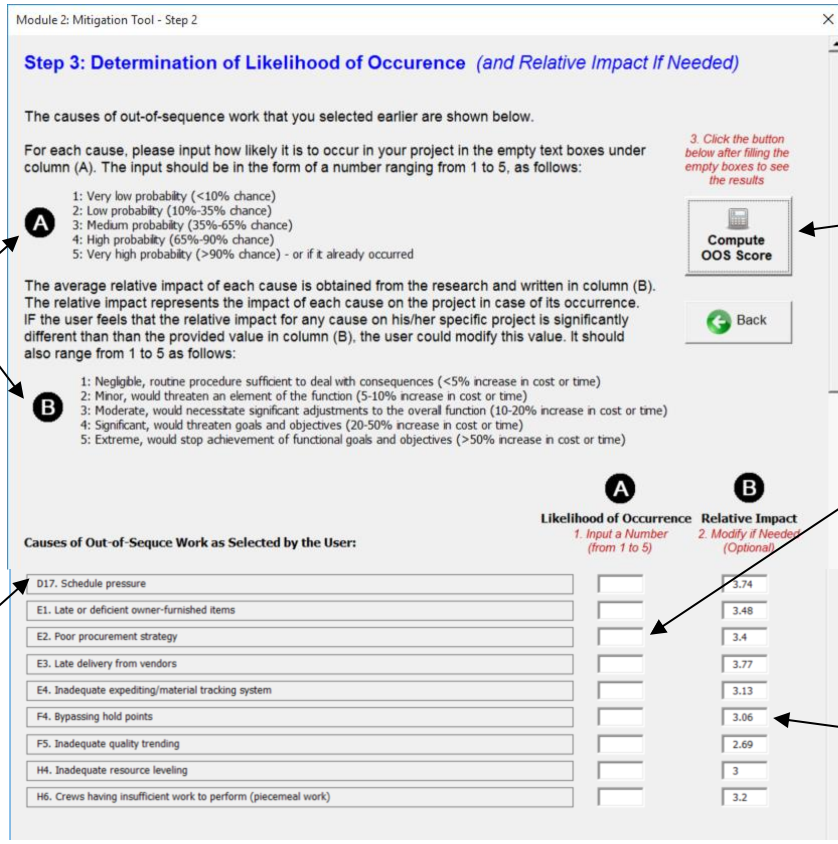
In this step, the user is shown his/her selected causes of OOS with textboxes in front of each causes. The user is required to input the likelihood of occurrence of each OOS cause in the corresponding textboxes. This input should be a number from 1 to 5 as described in the legend.

The average relative impact of each cause is obtained from the research and written automatically in front of each cause. IF the user feels that the relative impact of any cause on his/her project is significantly different than the provided value, the user has the ability to modify this value. It should range from 1 to 5 as well.

After the user inputs the likelihood of occurrence (and relative impact if applicable) for all causes, he/should click ***"Compute OOS Score"***.

Legends describing the meaning of the different likelihood of occurrence and relative impact values

The causes that are selected by the user

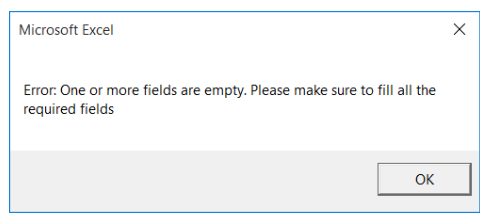


Takes the user to the "Results" form *(After he/she inputs the likelihood of occurrence)*

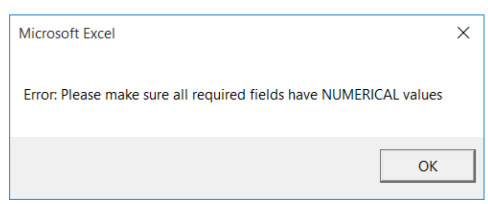
These textboxes are where the user is supposed to input the likelihood of occurrence

These textboxes are show the average relative impact of each cause as obtained from the research. The user can modify them is as seen appropriate by him/her depending on his/her project

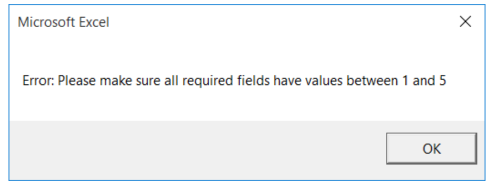
*If the user clicks **"Compute OOS Score"** without filling all required textboxes, the tool will not proceed to the next step and the following warning message will appear.*



*If the user clicks **"Compute OOS Score"** while one or more textboxes has characters or symbols by mistake instead of numbers, the tool will not proceed to the next step and the following warning message will appear.*



If the user clicks ***"Compute OOS Score"*** *while one or more textboxes have invalid numbers (higher than 5 or lower than 1), the tool will not proceed to the next step and the following warning message will appear.*



Results

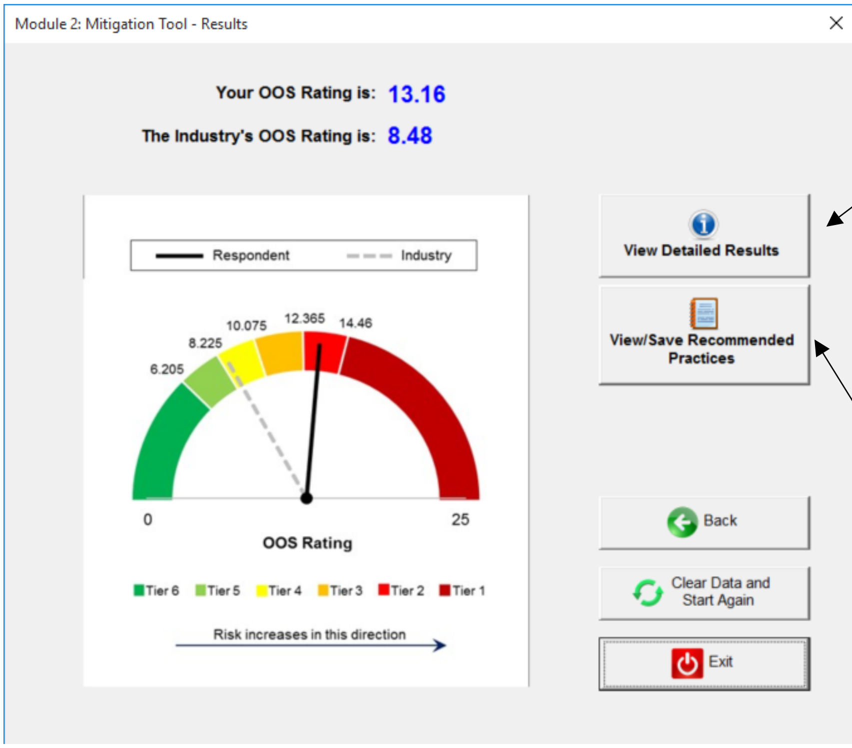
This form shows the resulting OOS Rating Score of the user's project in a color-coded dial. It also shows the industry's OOS Rating Score for the same selected causes of OOS. After knowing this, the user should have the objective of making his/her project's OOS Rating Score less than that of the industry: The user should also try to lower his/her OOS Rating Score so that the project becomes in a safer Tier (Tier 5 or 6).

The higher the OOS Rating Score the higher the risk. The OOS Rating Score takes values from 0 to 25.

The OOS Rating Score is calculated as follows:

$$OOS\ Rating\ Score = \frac{1}{n}\sum_{i \in K} P_i I_i$$

- $\boldsymbol{i}$: the code number of the OOS causes (1 to 88).
- $\boldsymbol{K}$ the set of only the OOS causes selected by the user.
- $\boldsymbol{P}$: the likelihood of occurrence of an OOS cause. The user inputs it (1 to 5).
- $\boldsymbol{I}$: the impact of the OOS cause in case of its occurrence. I is obtained from the results of the expert-based survey.
- $\boldsymbol{n}$: the number of OOS causes that are selected by the user. However, if the user selects less than 10 causes, n takes the value of 10.



Exports a PDF report showing more details about the project's OOS Rating Score

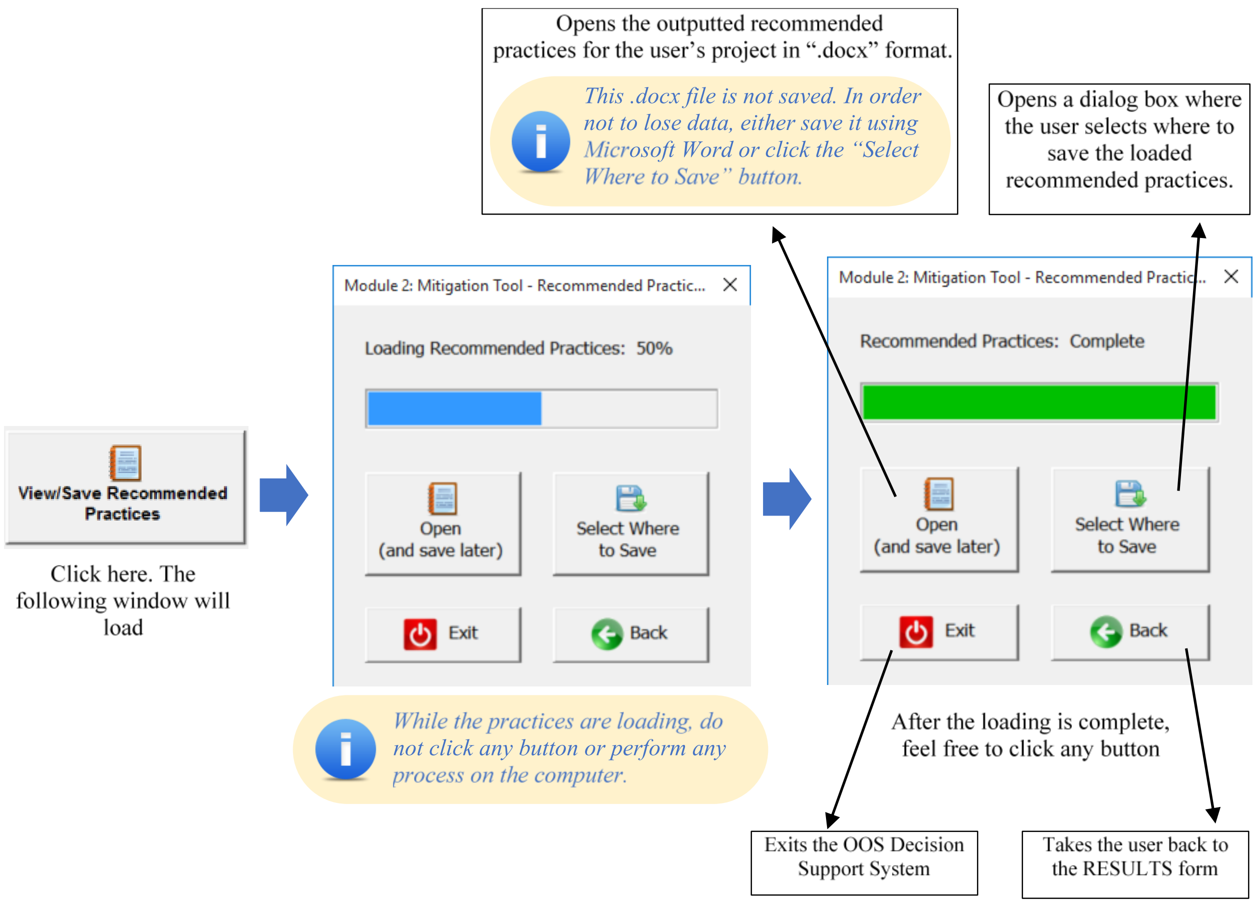
The user should <u>manually</u> save the exported report after it is opened.

It is recommended to export and save this report before viewing the best practices

Loads the corresponding **<u>recommended practices</u>**. The loading opens a separate form where the user has the option to open or save the best practices

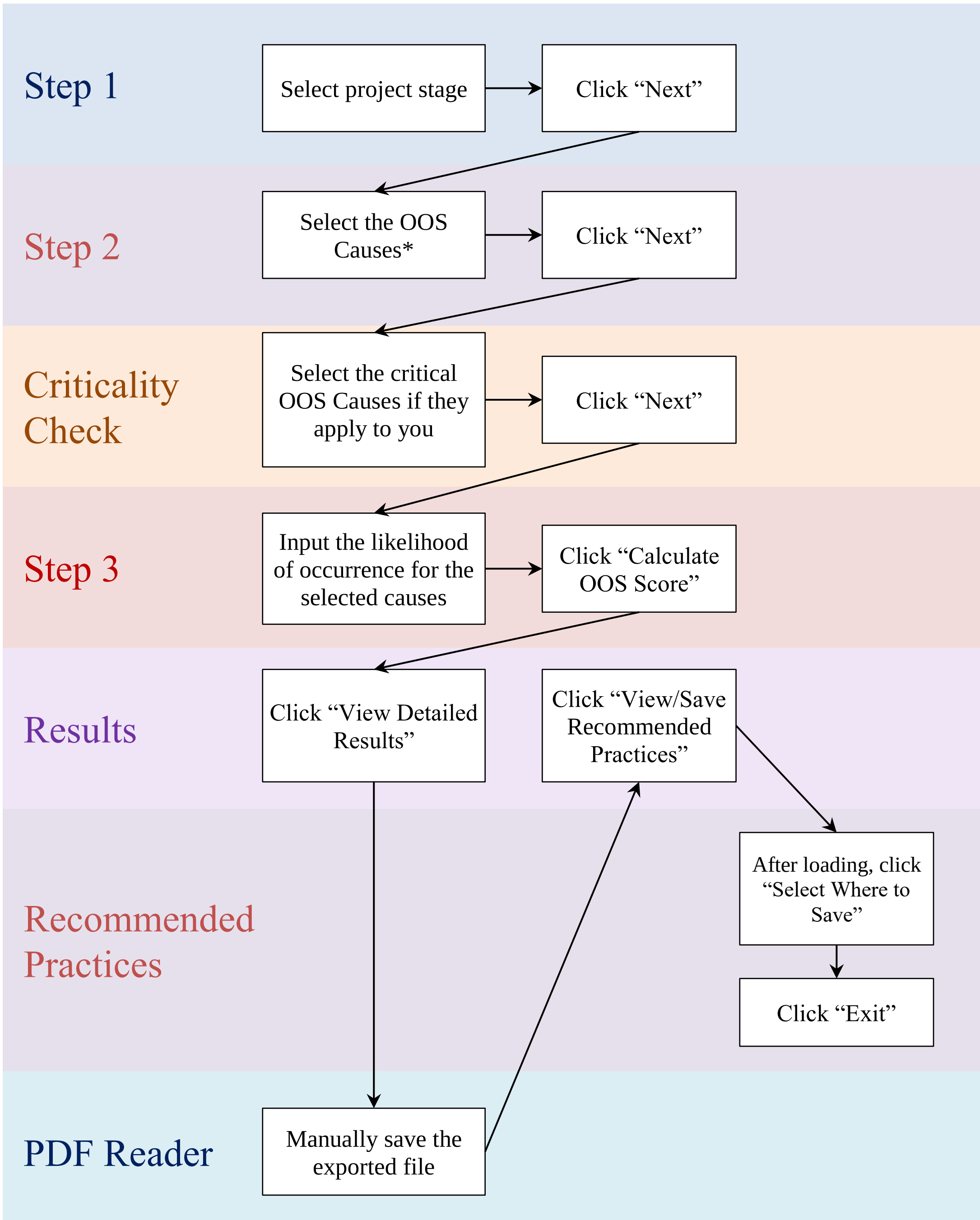
Loading and Exporting the Recommended Practices:

In the Results form, the user should click on **"View/Save Recommended Practices"** to be able to export the recommended practices as shown below. These practices are determined by the Tool based on the project stage and the inputted causes of OOS. As such, the tool will not export practices that are not applicable to the project stage that the user is currently at.



Summarized Steps for the Mitigation Tool

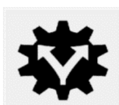
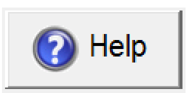
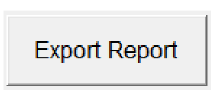
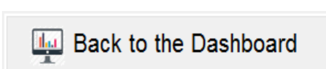
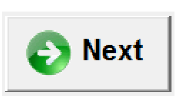
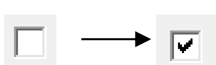
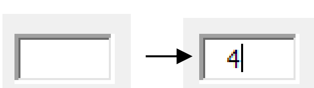
The following are the recommended steps to take when using the Mitigation Tool.

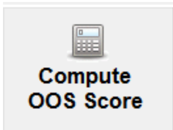
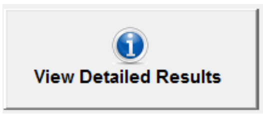
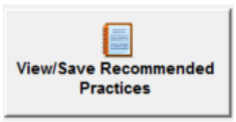
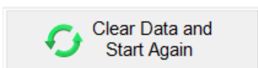
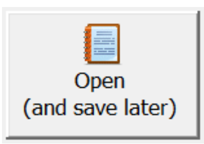
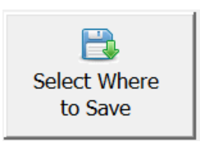


* The user can click on the text of the OOS Causes to learn more about these causes

The Different Buttons of the OOS Decision Support Tool

The following table lists the different buttons that can be found in the OOS Decision Support Tool and their functions. The table does not provide any new information as the different buttons were already discussed in detail earlier. The table provides just a simple summary.

Button	Function	Where it is found		
		Dashboard	Module 1	Module 2
	Starts Module 1 - Summary Reports	•		
	Starts Module 2 – Mitigation Tool	•		
	Opens the User's Guide in PDF format	•		
	Exits the OOS Decision Support Tool (any unsaved data will be lost)	•		•
	Opens a PDF file showing a report of the user's choice (from a corresponding dropdown menu)		•	
	Takes the user back to the Dashboard (any unsaved data will be lost)		•	•
	Takes the user to the next step in the Mitigation Tool			•
	Takes the user to the previous step in the Mitigation Tool			•
	This checkbox is in front of each cause of OOS. The user checks those causes which apply to his/her project.			•
	This is where the user inputs the likelihood of occurrence of the OOS cause.			•

Button	Function	Where it is found		
		Dashboard	Module 1	Module 2
	Computes the OOS Rating Score for the User's Project			•
	Opens a PDF file with details of the calculated OOS Rating Score			•
	Loads the recommended practices that are suitable to the user's project			•
	Clears the data and takes the user to the dashboard to start again			•
	Opens the outputted recommended practices for his/her project. The output is in ".docx" format.			•
	Opens a dialog box where the user selects where to save the outputted recommended practices for his/her project.			•

System Requirements

The computer running the OOS Decision Support Tool must have the following hardware and software requirements:

- Windows 7 or later (the tool was not tested on earlier versions but it could work)
- 2GB RAM or more
- Microsoft Word 2010 or later versions must be installed
- Microsoft Excel 2010 or later versions must be installed
- Software that reads PDF files (such as Adobe Acrobat Reader) must be installed

The OOS Decision Support Tool works on WINDOWS Operating System Only.
It does not work on MAC Operating System.

Error Handling

To avoid errors, please follow the procedures mentioned in this User's Guide.

Error while Starting the OOS Decision Support Tool

On rare occasions, an error might take place while starting the OOS Decision Support Tool showing the following error message:

Run Time Error 76; Path Not Found

If this error took place while starting the OOS Decision Support Tool, just click "End" and close the OOS Decision Support Tool (do not save any data). This error is resulting from the network and security settings set by the IT in your firm. In most firms this error does not take place. However, if it took place, then copy the OOS Decision Support Tool with all of its contents to an external USB stick. Open the OOS Decision Support Tool from the USB stick and it should work perfectly.

Error while Loading the Recommended Practices (Last Step)

On rare occasions, a warning message might pop up while loading the recommended practices. This warning message will show a warning number and will inform the user to close all Microsoft Word documents and try again. The user will be directed automatically to the previous menu where/she is able to click "View/Save Recommended Practices" and load the recommended practices again. The progress is not lost at this point.

If the warning takes place again:

- Close the OOS Decision Support Tool
- Close all the opened Microsoft Word files
- Start the OOS Decision Support Tool again. It should work properly.
- If the warning took place again, then restart the computer and use the OOS Decision Support Tool again. It should work properly.
- If the warning took place again, contact Ibrahim Abotaleb at abotaleb@utk.edu. Make sure to include the warning number in your email.

Appendix D:

The VBA Code for the OOS Decision Support Tool

The OOS Decision Support Tool is developed using a mix of Userforms, VBA, and Spreadsheets on Microsoft Excel. Userforms are dialog boxes that enable users to interact with the OOS Decision Support Tool in a user-friendly way without dealing with the equations or the formulations behind the multiple operations of the tool.

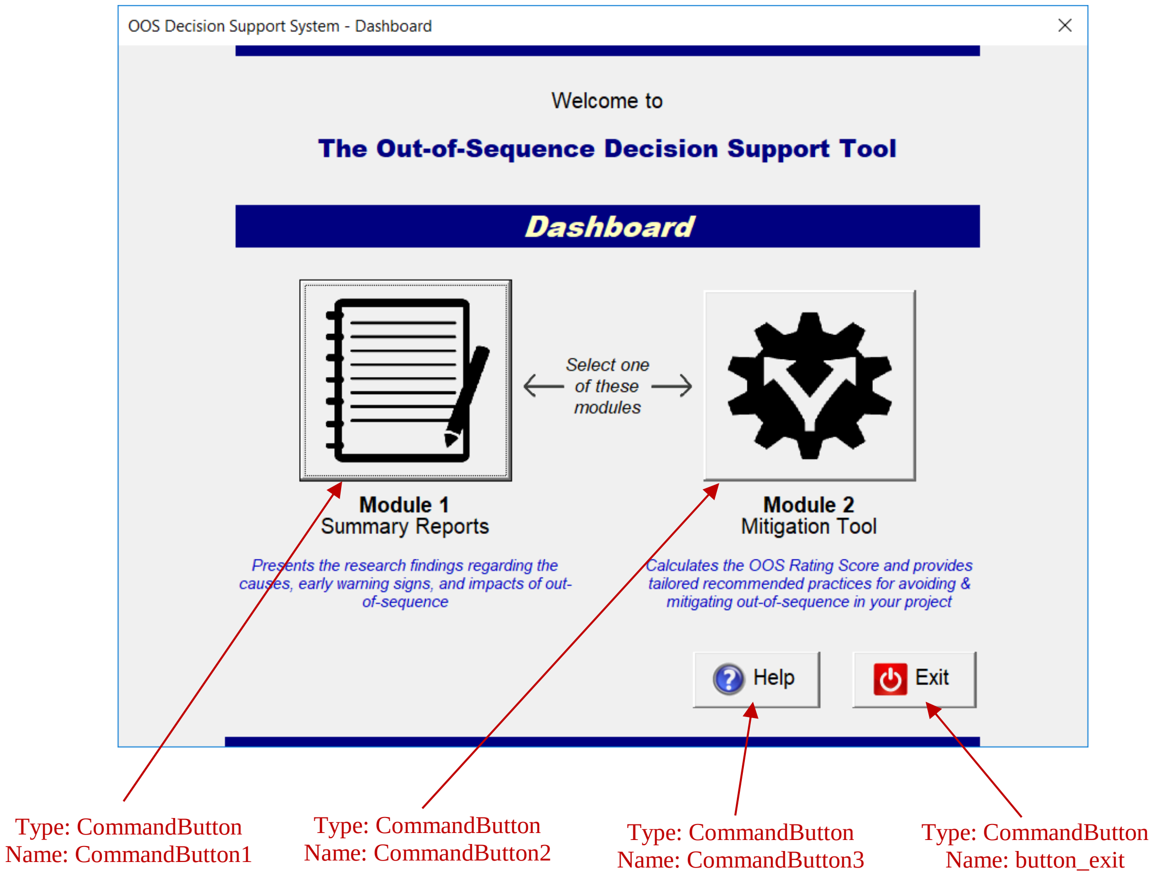
This appendix shows the used VBA code in the Userforms. It also shows the spreadsheets that build the Microsoft Excel file.

There are 8 Userforms. The following describes the name and function of each Userform:

Userform Name	Function
Dashboard	The opening dialog-box that the user sees when he starts the OOS Decision Support Tool. It provides the user with the option to enter Module 1 (Summary Reports) or Module 2 (Mitigation Tool).
Reports	This is the dialog-box that shows Module 1 (Summary Reports). Users will be able to select the type of report that he/she wishes to view from multiple available drop-down menus.
form0	Shows the first step in Module 2 (Mitigation Tool). It prompts the user to input the project stage that he/she is currently at.
form1	Shows the second step in Module 2 (Mitigation Tool). It shows the 88 causes of OOS and the user is able to check those that apply to his/her project.
form1_1	This dialog-box shows up if some of the critical OOS causes are not selected by the user in form1. It presents those unselected critical causes and the user can check any of them as he/she wishes.
form2	Shows the third step in Module 2 (Mitigation Tool). Shows the causes that are selected by the user in form1 and form1_1. It prompts the user to input the likelihood of occurrence of these causes in his/her project through text-boxes.
form3	Shows the resulting OOS score. It also has buttons to export more detailed reports and tailored best practices to prevent and mitigate OOS in his/her specific project.
Best_Practices_Loading	Shows up if the user clicks on “View/Save Recommended Practices” in form3. Shows a “loading” bar for the process of writing the recommended practices for the user’s project. Has buttons to view and/or save the outputted recommended practices.

For the Userform named “Dashboard”:

Userform Information:



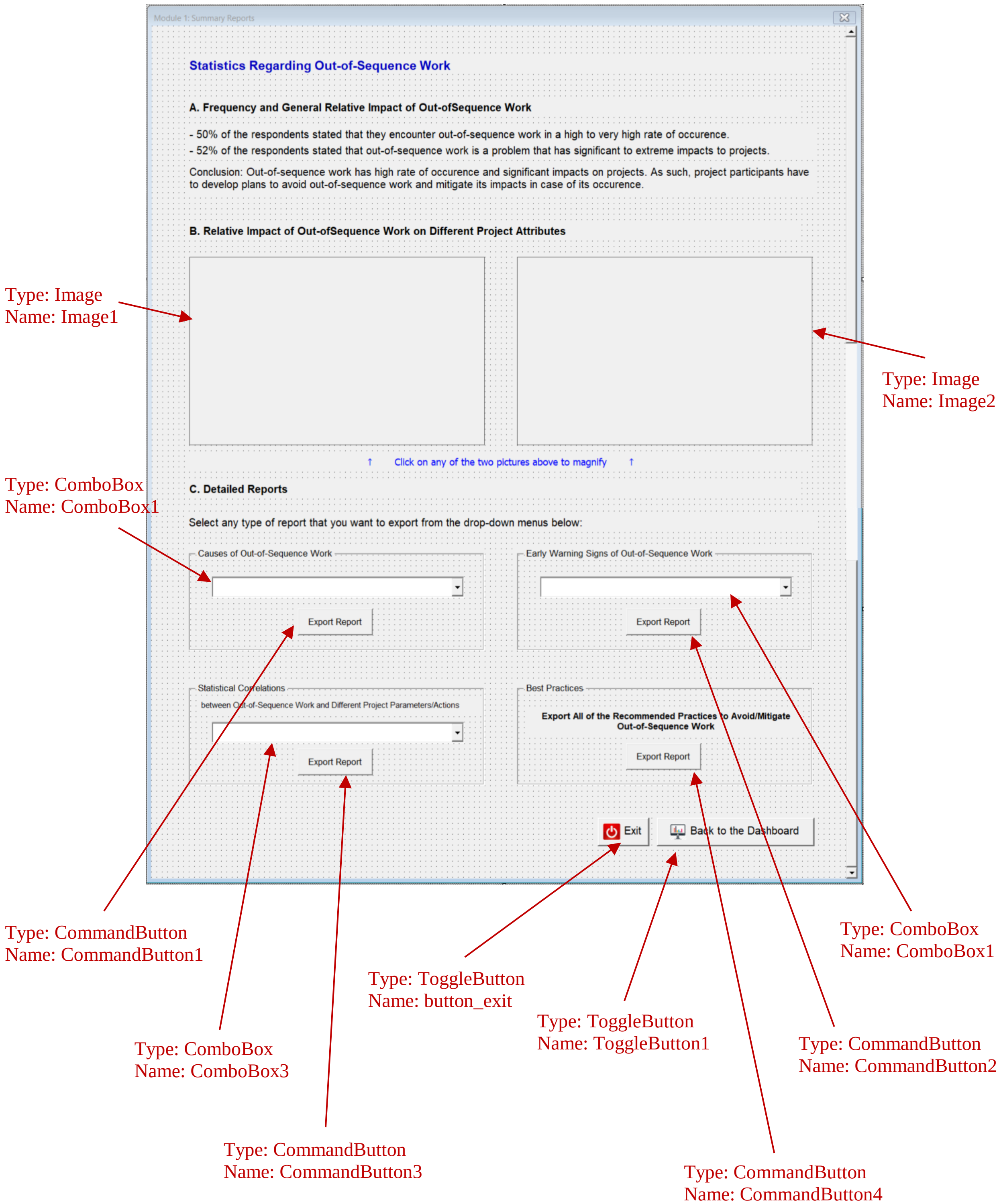
VBA Code Used in the Userform:

```
Private Sub button_exit_Click()
'a message box before exiting to prevent accidental exit
Dim msg, button, title, response
  msg = "Are you sure you want to exit?"
  button = vbYesNo + vbDefaultButton2
  title = "Confirm Exit"

  response = MsgBox(msg, button, title)
  If response = vbYes Then
    Unload Me
    Call clear_data
```

```
  Else
    Exit Sub
    'Unload form0
    'form0.Show
  End If

End Sub

Private Sub CommandButton1_Click()
    Unload Me
    Reports.Show
End Sub

Private Sub CommandButton2_Click()
    Unload Me
    form0.Show
End Sub

Private Sub CommandButton3_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Guide.pdf")
End Sub

Private Sub UserForm_Activate()
    Call clear_data
End Sub
```

For the Userform named “Reports”:

Userform Information:



VBA Code Used in the Userform:

```
Private Sub Image1_Click()


ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Pictures\impactsbig1.pdf")


End Sub


Private Sub Image2_Click()


ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Pictures\impactsbig2.pdf")


End Sub


Private Sub UserForm_Activate()


    Me.ScrollTop = 0


End Sub


Private Sub UserForm_Initialize()


Image1.Picture = LoadPicture(ThisWorkbook.Path & "\Supporting
Files\Pictures\impacts1-5.JPG")
Image2.Picture = LoadPicture(ThisWorkbook.Path & "\Supporting
Files\Pictures\impacts2-5.JPG")


With Reports.ComboBox1
    .AddItem "1. Causes of OOS - Categorized"
    .AddItem "2. Causes of OOS - Ranked by Likelihood of Occurrence"
    .AddItem "3. Causes of OOS - Ranked by Relative Impact"
    .AddItem "4. Causes of OOS - Ranked by Risk Rating"
    .AddItem "5. Comparison between Owners and Contractors"
End With
```

```
With Reports.ComboBox2
    .AddItem "1. Early Warning Signs of OOS - Categorized"
    .AddItem "2. Early Warning Signs of OOS - Ranked by Rating"
    .AddItem "3. Comparison between Owners and Contractors"
End With

With Reports.ComboBox3
    .AddItem "1. Impacts of OOS Correlated with Relevant Attributes"
    .AddItem "2. Causes and Early Warning Signs of OOS Correlated with
Relevant Attributes"
    .AddItem "3. Best Practices of OOS Correlated with Relevant
Attributes"
End With
End Sub

Private Sub CommandButton1_Click()
    If Reports.ComboBox1.Value = "1. Causes of OOS - Categorized" Then
        ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Ranking\1.1. Causes Organized By Category.pdf")
        Else
            If Reports.ComboBox1.Value = "2. Causes of OOS - Ranked by
Likelihood of Occurrence" Then
                ThisWorkbook.FollowHyperlink (ThisWorkbook.Path &
"\Supporting Files\Detailed Ranking\1.2. Overall Ranking By Likelihood
Of Occurence.pdf")
            Else
                If Reports.ComboBox1.Value = "3. Causes of OOS -
Ranked by Relative Impact" Then
                    ThisWorkbook.FollowHyperlink (ThisWorkbook.Path &
"\Supporting Files\Detailed Ranking\1.3. Overall Ranking By Relative
Impact.pdf")
                Else
                    If Reports.ComboBox1.Value = "4. Causes of OOS -
Ranked by Risk Rating" Then
                        ThisWorkbook.FollowHyperlink
(ThisWorkbook.Path & "\Supporting Files\Detailed Ranking\1.4. Overall
Ranking By Risk Rating.pdf")
```

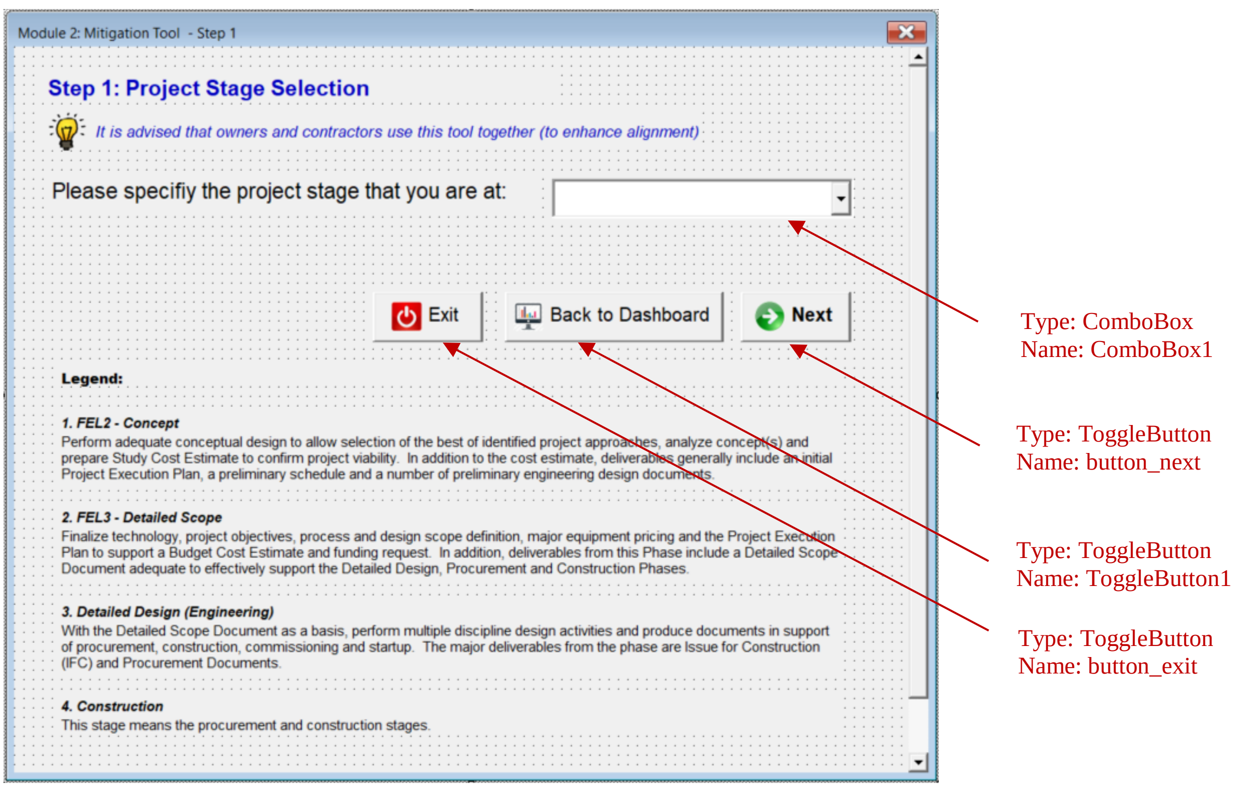
```
                    Else
                        If Reports.ComboBox1.Value = "5. Comparison
between Owners and Contractors" Then
                            ThisWorkbook.FollowHyperlink
(ThisWorkbook.Path & "\Supporting Files\Detailed Ranking\1.5.
Comparison Between Owners and Contractors.pdf")
                        Else
                            MsgBox "Please make a selection"
                        End If
                    End If
                End If
            End If
    End If
End Sub


Private Sub CommandButton2_Click()
    If Reports.ComboBox2.Value = "1. Early Warning Signs of OOS -
Categorized" Then
        ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Ranking\2.1. Categorized Early Warning Signs.pdf")
    Else
        If Reports.ComboBox2.Value = "2. Early Warning Signs of OOS -
Ranked by Rating" Then
            ThisWorkbook.FollowHyperlink (ThisWorkbook.Path &
"\Supporting Files\Detailed Ranking\2.2. Ranked Early Warning
Signs.pdf")
        Else
            If Reports.ComboBox2.Value = "3. Comparison between Owners
and Contractors" Then
                ThisWorkbook.FollowHyperlink (ThisWorkbook.Path &
"\Supporting Files\Detailed Ranking\2.3. Early Warning Signs
Comparison.pdf")
            Else
                 MsgBox "Please make a selection"
            End If
        End If
    End If
End Sub
```

```
Private Sub CommandButton3_Click()
    If Reports.ComboBox3.Value = "1. Impacts of OOS Correlated with
Relevant Attributes" Then
        ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Ranking\3.1. Correlations - Impacts.pdf")
    Else
        If Reports.ComboBox3.Value = "2. Causes and Early Warning
Signs of OOS Correlated with Relevant Attributes" Then
            ThisWorkbook.FollowHyperlink (ThisWorkbook.Path &
"\Supporting Files\Detailed Ranking\3.2. Correlations - Causes And
Warning Signs.pdf")
        Else
            If Reports.ComboBox3.Value = "3. Best Practices of OOS
Correlated with Relevant Attributes" Then
                ThisWorkbook.FollowHyperlink (ThisWorkbook.Path &
"\Supporting Files\Detailed Ranking\3.3. Correlations - Best
Practices.pdf")
            Else
                MsgBox "Please make a selection"
            End If
        End If
    End If
End Sub

Private Sub CommandButton4_Click()
    ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Ranking\4. All Recommended Practices.pdf")
End Sub

Private Sub ToggleButton1_Click()
    Unload Me
    Dashboard.Show
End Sub

Private Sub button_exit_Click()
'a message box before exiting to prevent accidental exit
```

```
Dim msg, button, title, response
  msg = "Are you sure you want to exit?"
  button = vbYesNo + vbDefaultButton2
  title = "Confirm Exit"

  response = MsgBox(msg, button, title)
  If response = vbYes Then
    Unload Me
    Call clear_data
  Else
  End If

End Sub
```

For the Userform named "form0":

Userform Information:



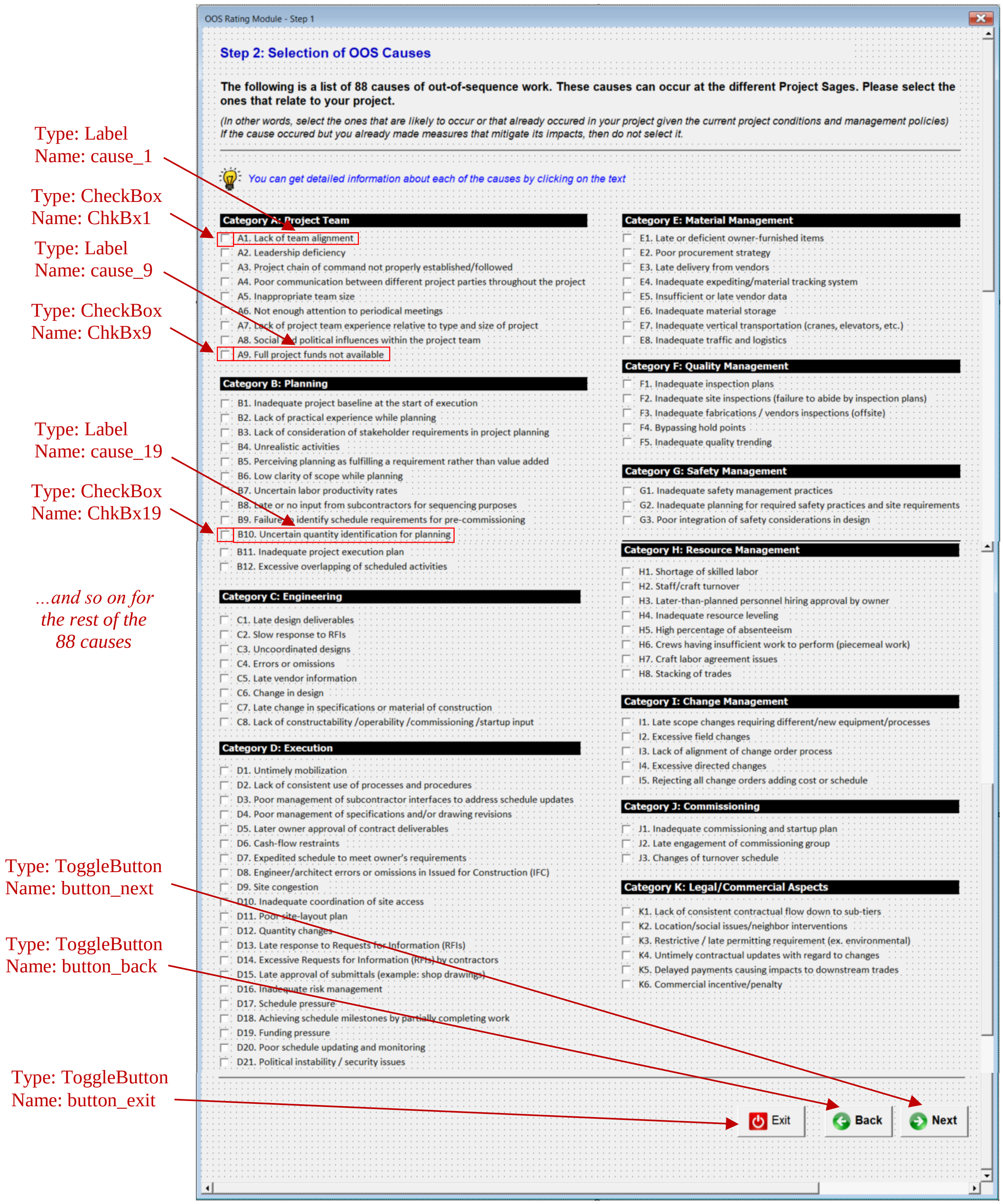
VBA Code Used in the Userform:

```
Private Sub button_exit_Click()

'a message box before exiting to prevent accidental exit
Dim msg, button, title, response
  msg = "Are you sure you want to exit?"
  button = vbYesNo + vbDefaultButton2
  title = "Confirm Exit"

  response = MsgBox(msg, button, title)
  If response = vbYes Then
    Unload Me
    Call clear_data
  Else
    Exit Sub
    'Unload form0
    'form0.Show
  End If

End Sub

Private Sub button_next_Click()

If ComboBox1.Value = "1. Concept (FEL 2)" Or ComboBox1.Value = "2.
Detailed Scope (FEL 3)" Or ComboBox1.Value = "3. Design" Or
ComboBox1.Value = "4. Construction" Then
    'copy the selected project stage to cell B10 in "Database2"
worksheet
    Worksheets("Database2").Cells(10, 1).Value = Me.ComboBox1.Value

    'Load the next page
    Unload Me
    form1.Show
Else
    'form0.button_next.Value = False
```

```
    MsgBox "Please select one of the choices and do not edit its
wording"

End If

End Sub

Private Sub ToggleButton1_Click()
    Unload Me
    Dashboard.Show
End Sub

Private Sub UserForm_Initialize()

With form0.ComboBox1
    .AddItem "1. Concept (FEL 2)"
    .AddItem "2. Detailed Scope (FEL 3)"
    .AddItem "3. Design"
    .AddItem "4. Construction"
End With

End Sub
```

For the Userform named “form1”:

Userform Information:



VBA Code Used in the Userform:

```
Private Sub ChkBx51_Click()


End Sub


'deactivates the X close button
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As
Integer)
        If CloseMode = 0 Then Cancel = True
End Sub


Private Sub button_back_Click()


Unload Me
form0.Show


End Sub


Private Sub button_exit_Click()


'a message box before exiting to prevent accidental exit
Dim msg, button, title, response
  msg = "Are you sure you want to exit?"
  button = vbYesNo + vbDefaultButton2
  title = "Confirm Exit"


  response = MsgBox(msg, button, title)
  If response = vbYes Then
    Unload Me
    Call clear_data
  Else
    Exit Sub
    'Unload form0
    'form0.Show
```

```
  End If

Unload Me

End Sub

Private Sub button_next_Click()

'clear database first
Worksheets("Database").Range("E2:K89").ClearContents

Dim iRow As Long
Dim ws As Worksheet
Set ws = Worksheets("Database")

'find first empty row in database
'iRow = ws.Cells.Find(What:="*", SearchOrder:=xlRows,
SearchDirection:=xlPrevious, LookIn:=xlValues).Row + 1

'copy the value of the checkboxes to the database
ws.Cells(2, 5).Value = Me.ChkBx1.Value
ws.Cells(3, 5).Value = Me.ChkBx2.Value
ws.Cells(4, 5).Value = Me.ChkBx3.Value
ws.Cells(5, 5).Value = Me.ChkBx4.Value
ws.Cells(6, 5).Value = Me.ChkBx5.Value
ws.Cells(7, 5).Value = Me.ChkBx6.Value
ws.Cells(8, 5).Value = Me.ChkBx7.Value
ws.Cells(9, 5).Value = Me.ChkBx8.Value
ws.Cells(10, 5).Value = Me.ChkBx9.Value
ws.Cells(11, 5).Value = Me.ChkBx10.Value
ws.Cells(12, 5).Value = Me.ChkBx11.Value
ws.Cells(13, 5).Value = Me.ChkBx12.Value
ws.Cells(14, 5).Value = Me.ChkBx13.Value
ws.Cells(15, 5).Value = Me.ChkBx14.Value
ws.Cells(16, 5).Value = Me.ChkBx15.Value
```

```
ws.Cells(17, 5).Value = Me.ChkBx16.Value
ws.Cells(18, 5).Value = Me.ChkBx17.Value
ws.Cells(19, 5).Value = Me.ChkBx18.Value
ws.Cells(20, 5).Value = Me.ChkBx19.Value
ws.Cells(21, 5).Value = Me.ChkBx20.Value
ws.Cells(22, 5).Value = Me.ChkBx21.Value
ws.Cells(23, 5).Value = Me.ChkBx22.Value
ws.Cells(24, 5).Value = Me.ChkBx23.Value
ws.Cells(25, 5).Value = Me.ChkBx24.Value
ws.Cells(26, 5).Value = Me.ChkBx25.Value
ws.Cells(27, 5).Value = Me.ChkBx26.Value
ws.Cells(28, 5).Value = Me.ChkBx27.Value
ws.Cells(29, 5).Value = Me.ChkBx28.Value
ws.Cells(30, 5).Value = Me.ChkBx29.Value
ws.Cells(31, 5).Value = Me.ChkBx30.Value
ws.Cells(32, 5).Value = Me.ChkBx31.Value
ws.Cells(33, 5).Value = Me.ChkBx32.Value
ws.Cells(34, 5).Value = Me.ChkBx33.Value
ws.Cells(35, 5).Value = Me.ChkBx34.Value
ws.Cells(36, 5).Value = Me.ChkBx35.Value
ws.Cells(37, 5).Value = Me.ChkBx36.Value
ws.Cells(38, 5).Value = Me.ChkBx37.Value
ws.Cells(39, 5).Value = Me.ChkBx38.Value
ws.Cells(40, 5).Value = Me.ChkBx39.Value
ws.Cells(41, 5).Value = Me.ChkBx40.Value
ws.Cells(42, 5).Value = Me.ChkBx41.Value
ws.Cells(43, 5).Value = Me.ChkBx42.Value
ws.Cells(44, 5).Value = Me.ChkBx43.Value
ws.Cells(45, 5).Value = Me.ChkBx44.Value
ws.Cells(46, 5).Value = Me.ChkBx45.Value
ws.Cells(47, 5).Value = Me.ChkBx46.Value
ws.Cells(48, 5).Value = Me.ChkBx47.Value
ws.Cells(49, 5).Value = Me.ChkBx48.Value
ws.Cells(50, 5).Value = Me.ChkBx49.Value
```

```
ws.Cells(51, 5).Value = Me.ChkBx50.Value
ws.Cells(52, 5).Value = Me.ChkBx51.Value
ws.Cells(53, 5).Value = Me.ChkBx52.Value
ws.Cells(54, 5).Value = Me.ChkBx53.Value
ws.Cells(55, 5).Value = Me.ChkBx54.Value
ws.Cells(56, 5).Value = Me.ChkBx55.Value
ws.Cells(57, 5).Value = Me.ChkBx56.Value
ws.Cells(58, 5).Value = Me.ChkBx57.Value
ws.Cells(59, 5).Value = Me.ChkBx58.Value
ws.Cells(60, 5).Value = Me.ChkBx59.Value
ws.Cells(61, 5).Value = Me.ChkBx60.Value
ws.Cells(62, 5).Value = Me.ChkBx61.Value
ws.Cells(63, 5).Value = Me.ChkBx62.Value
ws.Cells(64, 5).Value = Me.ChkBx63.Value
ws.Cells(65, 5).Value = Me.ChkBx64.Value
ws.Cells(66, 5).Value = Me.ChkBx65.Value
ws.Cells(67, 5).Value = Me.ChkBx66.Value
ws.Cells(68, 5).Value = Me.ChkBx67.Value
ws.Cells(69, 5).Value = Me.ChkBx68.Value
ws.Cells(70, 5).Value = Me.ChkBx69.Value
ws.Cells(71, 5).Value = Me.ChkBx70.Value
ws.Cells(72, 5).Value = Me.ChkBx71.Value
ws.Cells(73, 5).Value = Me.ChkBx72.Value
ws.Cells(74, 5).Value = Me.ChkBx73.Value
ws.Cells(75, 5).Value = Me.ChkBx74.Value
ws.Cells(76, 5).Value = Me.ChkBx75.Value
ws.Cells(77, 5).Value = Me.ChkBx76.Value
ws.Cells(78, 5).Value = Me.ChkBx77.Value
ws.Cells(79, 5).Value = Me.ChkBx78.Value
ws.Cells(80, 5).Value = Me.ChkBx79.Value
ws.Cells(81, 5).Value = Me.ChkBx80.Value
ws.Cells(82, 5).Value = Me.ChkBx81.Value
ws.Cells(83, 5).Value = Me.ChkBx82.Value
ws.Cells(84, 5).Value = Me.ChkBx83.Value
```

```
ws.Cells(85, 5).Value = Me.ChkBx84.Value
ws.Cells(86, 5).Value = Me.ChkBx85.Value
ws.Cells(87, 5).Value = Me.ChkBx86.Value
ws.Cells(88, 5).Value = Me.ChkBx87.Value
ws.Cells(89, 5).Value = Me.ChkBx88.Value

'error message in case the user did not make any selection
If ws.Cells(90, 5).Value = 0 Then
    MsgBox "Please select at least one case from the list"
    Unload Me
    form1.Show
End If

'obtain the names and impacts of the selected causes from the big
table
'and put them in a separate table of their own
'iRow1 = 2
iRow2 = 2
For iRow = 2 To 89
If ws.Cells(iRow, 5) = True Then
    ws.Cells(iRow2, 8).Value = ws.Cells(iRow, 1)
    ws.Cells(iRow2, 9).Value = ws.Cells(iRow, 2)
    ws.Cells(iRow2, 10).Value = ws.Cells(iRow, 4)
    iRow2 = iRow2 + 1
    End If
Next iRow

'Continue from here
'Continue from here
'Continue from here
'Continue from here
'Continue from here
'Continue from here
'Continue from here
'Continue from here
```

```
'Continue from here
'copy those critical acticivities not selected by user in a separate
table
Dim Selected_Causes As Long
Dim Added_Causes As Long
Dim rr As Long

Selected_Causes = ws.Cells(90, 5).Value
Added_Causes = 0

'start pasting from the row after where the selected causes ended (but
leave a blank row)
rr = Selected_Causes + 2

For iRow = 3 To 90
    If Worksheets("Database2").Cells(iRow, 14).Value = 1 Then
        Worksheets("Database").Cells(rr, 8).Value =
Worksheets("Database2").Cells(iRow, 6).Value
        Worksheets("Database").Cells(rr, 9).Value =
Worksheets("Database2").Cells(iRow, 7).Value
        Worksheets("Database").Cells(rr, 10).Value =
Worksheets("Database2").Cells(iRow, 11).Value
        rr = rr + 1
        Added_Causes = Added_Causes + 1
        End If
Next iRow

Worksheets("Database").Cells(91, 5).Value = Added_Causes

Unload Me
form1_1.Show

End Sub

Private Sub Label1_Click()
```

```
End Sub

Private Sub cause_1_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\1.pdf")
End Sub

Private Sub cause_2_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\2.pdf")
End Sub

Private Sub cause_3_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\3.pdf")
End Sub

Private Sub cause_4_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\4.pdf")
End Sub

Private Sub cause_5_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\5.pdf")
End Sub

Private Sub cause_6_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\6.pdf")
End Sub

Private Sub cause_7_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\7.pdf")
End Sub
```

```
Private Sub cause_8_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\8.pdf")
End Sub

Private Sub cause_9_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\9.pdf")
End Sub

Private Sub cause_10_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\10.pdf")
End Sub

Private Sub cause_11_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\11.pdf")
End Sub

Private Sub cause_12_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\12.pdf")
End Sub

Private Sub cause_13_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\13.pdf")
End Sub

Private Sub cause_14_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\14.pdf")
End Sub
```

```
Private Sub cause_15_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\15.pdf")
End Sub

Private Sub cause_16_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\16.pdf")
End Sub

Private Sub cause_17_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\17.pdf")
End Sub

Private Sub cause_18_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\18.pdf")
End Sub

Private Sub cause_19_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\19.pdf")
End Sub

Private Sub cause_20_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\20.pdf")
End Sub

Private Sub cause_21_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\21.pdf")
End Sub

Private Sub cause_22_Click()
```

```
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\22.pdf")

End Sub


Private Sub cause_23_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\23.pdf")

End Sub


Private Sub cause_24_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\24.pdf")

End Sub


Private Sub cause_25_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\25.pdf")

End Sub


Private Sub cause_26_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\26.pdf")

End Sub


Private Sub cause_27_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\27.pdf")

End Sub


Private Sub cause_28_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\28.pdf")

End Sub


Private Sub cause_29_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\29.pdf")
```

```
End Sub

Private Sub cause_30_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\30.pdf")
End Sub

Private Sub cause_31_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\31.pdf")
End Sub

Private Sub cause_32_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\32.pdf")
End Sub

Private Sub cause_33_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\33.pdf")
End Sub

Private Sub cause_34_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\34.pdf")
End Sub

Private Sub cause_35_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\35.pdf")
End Sub

Private Sub cause_36_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\36.pdf")
End Sub
```

```
Private Sub cause_37_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\37.pdf")

End Sub


Private Sub cause_38_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\38.pdf")

End Sub


Private Sub cause_39_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\39.pdf")

End Sub


Private Sub cause_40_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\40.pdf")

End Sub


Private Sub cause_41_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\41.pdf")

End Sub


Private Sub cause_42_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\42.pdf")

End Sub


Private Sub cause_43_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\43.pdf")

End Sub
```

```
Private Sub cause_44_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\44.pdf")

End Sub


Private Sub cause_45_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\45.pdf")

End Sub


Private Sub cause_46_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
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End Sub


Private Sub cause_47_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\47.pdf")

End Sub


Private Sub cause_48_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\48.pdf")

End Sub


Private Sub cause_49_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\49.pdf")

End Sub


Private Sub cause_50_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\50.pdf")

End Sub


Private Sub cause_51_Click()
```

```
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\51.pdf")

End Sub


Private Sub cause_52_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\52.pdf")

End Sub


Private Sub cause_53_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
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End Sub


Private Sub cause_54_Click()

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Files\Detailed Causes\54.pdf")

End Sub


Private Sub cause_55_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\55.pdf")

End Sub


Private Sub cause_56_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\56.pdf")

End Sub


Private Sub cause_57_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\57.pdf")

End Sub


Private Sub cause_58_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\58.pdf")
```

```
End Sub

Private Sub cause_59_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\59.pdf")
End Sub

Private Sub cause_60_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\60.pdf")
End Sub

Private Sub cause_61_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\61.pdf")
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Private Sub cause_62_Click()
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Private Sub cause_63_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
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Private Sub cause_64_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\64.pdf")
End Sub

Private Sub cause_65_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\65.pdf")
End Sub
```

```
Private Sub cause_66_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\66.pdf")

End Sub


Private Sub cause_67_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\67.pdf")

End Sub


Private Sub cause_68_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\68.pdf")

End Sub


Private Sub cause_69_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\69.pdf")

End Sub


Private Sub cause_70_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\70.pdf")

End Sub


Private Sub cause_71_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\71.pdf")

End Sub


Private Sub cause_72_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\72.pdf")

End Sub
```

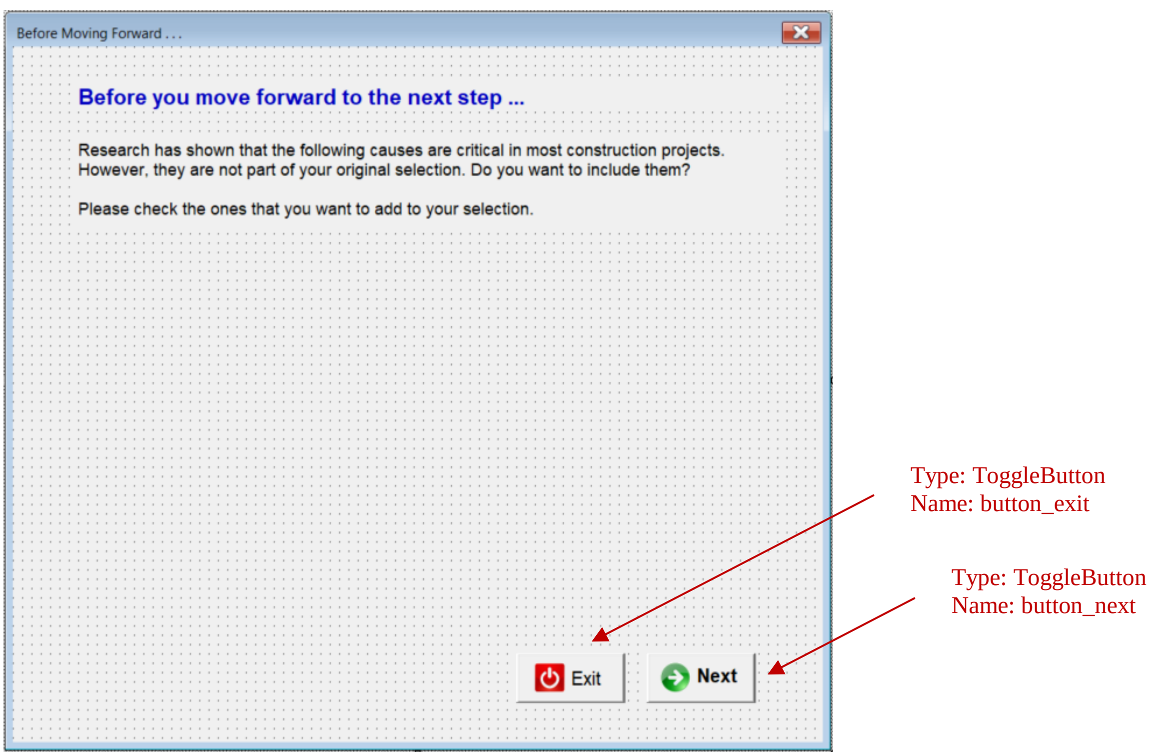
```
Private Sub cause_73_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\73.pdf")

End Sub


Private Sub cause_74_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\74.pdf")

End Sub


Private Sub cause_75_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\75.pdf")

End Sub


Private Sub cause_76_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\76.pdf")

End Sub


Private Sub cause_77_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\77.pdf")

End Sub


Private Sub cause_78_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\78.pdf")

End Sub


Private Sub cause_79_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\79.pdf")

End Sub


Private Sub cause_80_Click()
```

```
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\80.pdf")

End Sub


Private Sub cause_81_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\81.pdf")

End Sub


Private Sub cause_82_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\82.pdf")

End Sub


Private Sub cause_83_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\83.pdf")

End Sub


Private Sub cause_84_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\84.pdf")

End Sub


Private Sub cause_85_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\85.pdf")

End Sub


Private Sub cause_86_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\86.pdf")

End Sub


Private Sub cause_87_Click()

ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\87.pdf")
```

```
End Sub

Private Sub cause_88_Click()
ThisWorkbook.FollowHyperlink (ThisWorkbook.Path & "\Supporting
Files\Detailed Causes\88.pdf")
End Sub


Private Sub UserForm_Activate()

End Sub
```

For the Userform named “form1_1”:

Userform Information:



VBA Code Used in the Userform:

```
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As
Integer)
        If CloseMode = 0 Then Cancel = True
End Sub



Private Sub button_exit_Click()

'a message box before exiting to prevent accidental exit
Dim msg, button, title, response
  msg = "Are you sure you want to exit?"
  button = vbYesNo + vbDefaultButton2
  title = "Confirm Exit"

  response = MsgBox(msg, button, title)
  If response = vbYes Then
    Unload Me
    Call clear_data
  Else
    Exit Sub
    'Unload form0
    'form0.Show
  End If

Unload Me

End Sub



Private Sub Label1_Click()

End Sub
```

```
Private Sub UserForm_Activate()

Set ws = Worksheets("Database")

'count the number of additional OOS causes selected by the user
'additional causes are the critical ones that are not selected by the user
'additional_ones = ws.Cells(91, 5).Value

'create the textboxes containing the selected OOS causes
'form2.text80.Text = ws.Cells(2, 2)
Dim text2 As Control
Dim text3 As Control
Dim i As Long
Dim starting_row As Long
Dim ending_row As Long

starting_row = ws.Cells(90, 5) + 2
ending_row = starting_row + ws.Cells(91, 5)

For i = starting_row To (ending_row - 1)
    Set text2 = Controls.Add("Forms.TextBox.1")
    With text2
        .Name = "text" & i
        .Text = ws.Cells(i, 9)
        .Top = 10 * (i - starting_row + 1) * 2 + 150
        .Left = 42
        .BackColor = &HFFFFFF
        .Width = 400
        .Height = 17
        .BackStyle = 0
        .BorderStyle = 1
        .Font.Size = 11
        .Font.Name = "Calibri"
    End With
```

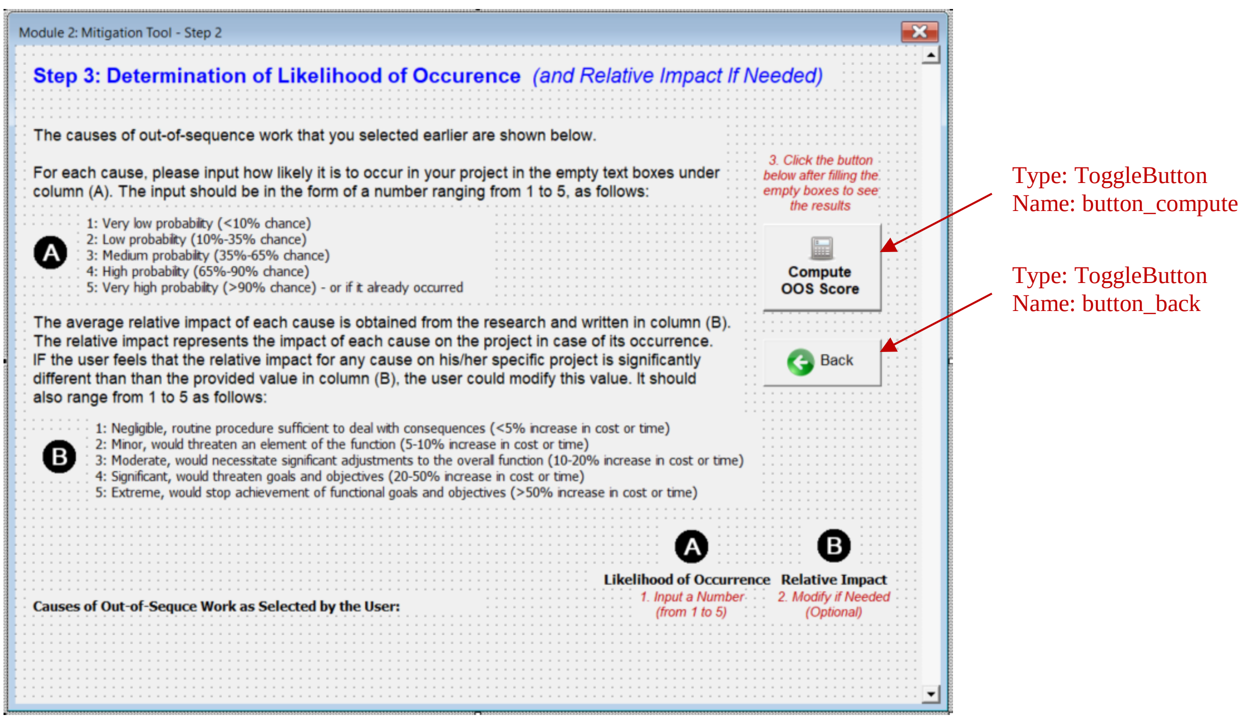
```
Next i

'create the corresponding texboxes where the users input the
likelihood
Dim j
For j = starting_row To (ending_row - 1)
    Set text3 = Controls.Add("Forms.CheckBox.1")
    With text3
        .Name = "checkboxx" & j
        .Top = 10 * (j - starting_row + 1) * 2 + 153
        .Left = 450
        .BackColor = &H8000000F
        .Width = 12
        .Height = 12
        '.BackStyle = 1
        '.BorderStyle = 0
        '.TextAlign = 1
        '.Text = ws.Cells(j, 10).Text
    End With
Next j


End Sub


Private Sub button_next_Click()
Dim ii As Long
Dim starting_row As Long
Dim ending_row As Long

starting_row = Worksheets("Database").Cells(90, 5) + 2
ending_row = starting_row + Worksheets("Database").Cells(91, 5)
ii = 1

For k = starting_row To (ending_row - 1)
```

```
    If form1_1.Controls.Item(form1_1.Controls.Count + k -
ending_row).Value = 0 Then
        Worksheets("Database").Cells(k, 8).Clear
        Worksheets("Database").Cells(k, 9).Clear
        Worksheets("Database").Cells(k, 10).Clear
    End If
    ii = ii + 1
Next k

Set ws = Worksheets("Database")
'there might be blank rows if the user does not select all critical
causes
'so to remove the blank rows we are going to delete the whole table
and write it again
'first we need to make sure the "trigger" column has "True" on all the
selected causes
Dim u
For u = 2 To 89
    If Application.WorksheetFunction.CountIf(ws.Range("H2:H89"),
ws.Cells(u, 1)) = 1 Then
        ws.Cells(u, 5).Value = 1
    Else
        ws.Cells(u, 5).Value = 0
    End If
Next u

'then we delete all cells of the new table
ws.Range("H2:J89").Clear

'then we re-write the table from scratch
'obtain the names and impacts of the selected causes from the big
table
'and put them in a separate table of their own
Dim iiRow
Dim iiRow2
iiRow2 = 2
```

```
For iiRow = 2 To 89
If ws.Cells(iiRow, 5).Value = 1 Then
    ws.Cells(iiRow2, 8).Value = ws.Cells(iiRow, 1)
    ws.Cells(iiRow2, 9).Value = ws.Cells(iiRow, 2)
    ws.Cells(iiRow2, 10).Value = ws.Cells(iiRow, 4)
    iiRow2 = iiRow2 + 1
    End If
Next iiRow

Unload Me
form2.Show

End Sub
```

<u>For the Userform named “form2”:</u>

Userform Information:



VBA Code Used in the Userform:

```
Public oos_count As Integer

Private Sub button_back_Click()

Unload Me

Set ws = Worksheets("Database")

'this is in case the user visited form1 from form2
form1.ChkBx1.Value = ws.Cells(2, 5).Value
form1.ChkBx2.Value = ws.Cells(3, 5).Value
form1.ChkBx3.Value = ws.Cells(4, 5).Value
form1.ChkBx4.Value = ws.Cells(5, 5).Value
form1.ChkBx5.Value = ws.Cells(6, 5).Value
form1.ChkBx6.Value = ws.Cells(7, 5).Value
form1.ChkBx7.Value = ws.Cells(8, 5).Value
form1.ChkBx8.Value = ws.Cells(9, 5).Value
form1.ChkBx9.Value = ws.Cells(10, 5).Value
form1.ChkBx10.Value = ws.Cells(11, 5).Value
form1.ChkBx11.Value = ws.Cells(12, 5).Value
form1.ChkBx12.Value = ws.Cells(13, 5).Value
form1.ChkBx13.Value = ws.Cells(14, 5).Value
form1.ChkBx14.Value = ws.Cells(15, 5).Value
form1.ChkBx15.Value = ws.Cells(16, 5).Value
form1.ChkBx16.Value = ws.Cells(17, 5).Value
form1.ChkBx17.Value = ws.Cells(18, 5).Value
form1.ChkBx18.Value = ws.Cells(19, 5).Value
form1.ChkBx19.Value = ws.Cells(20, 5).Value
form1.ChkBx20.Value = ws.Cells(21, 5).Value
form1.ChkBx21.Value = ws.Cells(22, 5).Value
form1.ChkBx22.Value = ws.Cells(23, 5).Value
form1.ChkBx23.Value = ws.Cells(24, 5).Value
form1.ChkBx24.Value = ws.Cells(25, 5).Value
```

```
form1.ChkBx25.Value = ws.Cells(26, 5).Value
form1.ChkBx26.Value = ws.Cells(27, 5).Value
form1.ChkBx27.Value = ws.Cells(28, 5).Value
form1.ChkBx28.Value = ws.Cells(29, 5).Value
form1.ChkBx29.Value = ws.Cells(30, 5).Value
form1.ChkBx30.Value = ws.Cells(31, 5).Value
form1.ChkBx31.Value = ws.Cells(32, 5).Value
form1.ChkBx32.Value = ws.Cells(33, 5).Value
form1.ChkBx33.Value = ws.Cells(34, 5).Value
form1.ChkBx34.Value = ws.Cells(35, 5).Value
form1.ChkBx35.Value = ws.Cells(36, 5).Value
form1.ChkBx36.Value = ws.Cells(37, 5).Value
form1.ChkBx37.Value = ws.Cells(38, 5).Value
form1.ChkBx38.Value = ws.Cells(39, 5).Value
form1.ChkBx39.Value = ws.Cells(40, 5).Value
form1.ChkBx40.Value = ws.Cells(41, 5).Value
form1.ChkBx41.Value = ws.Cells(42, 5).Value
form1.ChkBx42.Value = ws.Cells(43, 5).Value
form1.ChkBx43.Value = ws.Cells(44, 5).Value
form1.ChkBx44.Value = ws.Cells(45, 5).Value
form1.ChkBx45.Value = ws.Cells(46, 5).Value
form1.ChkBx46.Value = ws.Cells(47, 5).Value
form1.ChkBx47.Value = ws.Cells(48, 5).Value
form1.ChkBx48.Value = ws.Cells(49, 5).Value
form1.ChkBx49.Value = ws.Cells(50, 5).Value
form1.ChkBx50.Value = ws.Cells(51, 5).Value
form1.ChkBx51.Value = ws.Cells(52, 5).Value
form1.ChkBx52.Value = ws.Cells(53, 5).Value
form1.ChkBx53.Value = ws.Cells(54, 5).Value
form1.ChkBx54.Value = ws.Cells(55, 5).Value
form1.ChkBx55.Value = ws.Cells(56, 5).Value
form1.ChkBx56.Value = ws.Cells(57, 5).Value
form1.ChkBx57.Value = ws.Cells(58, 5).Value
form1.ChkBx58.Value = ws.Cells(59, 5).Value
```

```
form1.ChkBx59.Value = ws.Cells(60, 5).Value
form1.ChkBx60.Value = ws.Cells(61, 5).Value
form1.ChkBx61.Value = ws.Cells(62, 5).Value
form1.ChkBx62.Value = ws.Cells(63, 5).Value
form1.ChkBx63.Value = ws.Cells(64, 5).Value
form1.ChkBx64.Value = ws.Cells(65, 5).Value
form1.ChkBx65.Value = ws.Cells(66, 5).Value
form1.ChkBx66.Value = ws.Cells(67, 5).Value
form1.ChkBx67.Value = ws.Cells(68, 5).Value
form1.ChkBx68.Value = ws.Cells(69, 5).Value
form1.ChkBx69.Value = ws.Cells(70, 5).Value
form1.ChkBx70.Value = ws.Cells(71, 5).Value
form1.ChkBx71.Value = ws.Cells(72, 5).Value
form1.ChkBx72.Value = ws.Cells(73, 5).Value
form1.ChkBx73.Value = ws.Cells(74, 5).Value
form1.ChkBx74.Value = ws.Cells(75, 5).Value
form1.ChkBx75.Value = ws.Cells(76, 5).Value
form1.ChkBx76.Value = ws.Cells(77, 5).Value
form1.ChkBx77.Value = ws.Cells(78, 5).Value
form1.ChkBx78.Value = ws.Cells(79, 5).Value
form1.ChkBx79.Value = ws.Cells(80, 5).Value
form1.ChkBx80.Value = ws.Cells(81, 5).Value
form1.ChkBx81.Value = ws.Cells(82, 5).Value
form1.ChkBx82.Value = ws.Cells(83, 5).Value
form1.ChkBx83.Value = ws.Cells(84, 5).Value
form1.ChkBx84.Value = ws.Cells(85, 5).Value
form1.ChkBx85.Value = ws.Cells(86, 5).Value
form1.ChkBx86.Value = ws.Cells(87, 5).Value
form1.ChkBx87.Value = ws.Cells(88, 5).Value
form1.ChkBx88.Value = ws.Cells(89, 5).Value


form1.Show
End Sub
```

```
Public Sub UserForm_Activate()

Set ws = Worksheets("Database")

'count the number of OOS causes selected by the user
oos_count = ws.Cells(92, 5)

'create the textboxes containing the selected OOS causes
'form2.text80.Text = ws.Cells(2, 2)
Dim text1 As Control
Dim i
Dim inew
inew = 1
For i = 1 To oos_count
    If ws.Cells(inew + 1, 9).Value = "" Then
        i = i - 1
    Else
        Set text1 = Controls.Add("Forms.TextBox.1")
        With text1
            .Name = "text" & i
            .Text = ws.Cells(inew + 1, 9)
            .Top = 10 * i * 2 + 380
            .Left = 12
            .BackColor = &HFFFFFF
            .Width = 410
            .Height = 15
            .BackStyle = 0
            .BorderStyle = 1
        End With
    End If
    inew = inew + 1
```

```
Next i

'create the corresponding texboxes where the users input the
likelihood
Dim j
Dim jnew
jnew = 1
For j = 1 To oos_count
    If ws.Cells(jnew + 1, 9).Value = "" Then
        j = j - 1
    Else
        Set text2 = Controls.Add("Forms.TextBox.1")
        With text2
            .Name = "likelihood" & j
            .Top = 10 * j * 2 + 380
            .Left = 440
            .BackColor = &H80000005
            .Width = 35
            .Height = 15
            .BackStyle = 1
            .BorderStyle = 0
            .TextAlign = 1
            .Text = ws.Cells(jnew + 1, 11).Text
        End With
    End If
    jnew = jnew + 1
Next j

'create the corresponding texboxes that show the impacts and the user
can edit them
Dim k
Dim knew
knew = 1
For k = 1 To oos_count
    If ws.Cells(knew + 1, 9).Value = "" Then
```

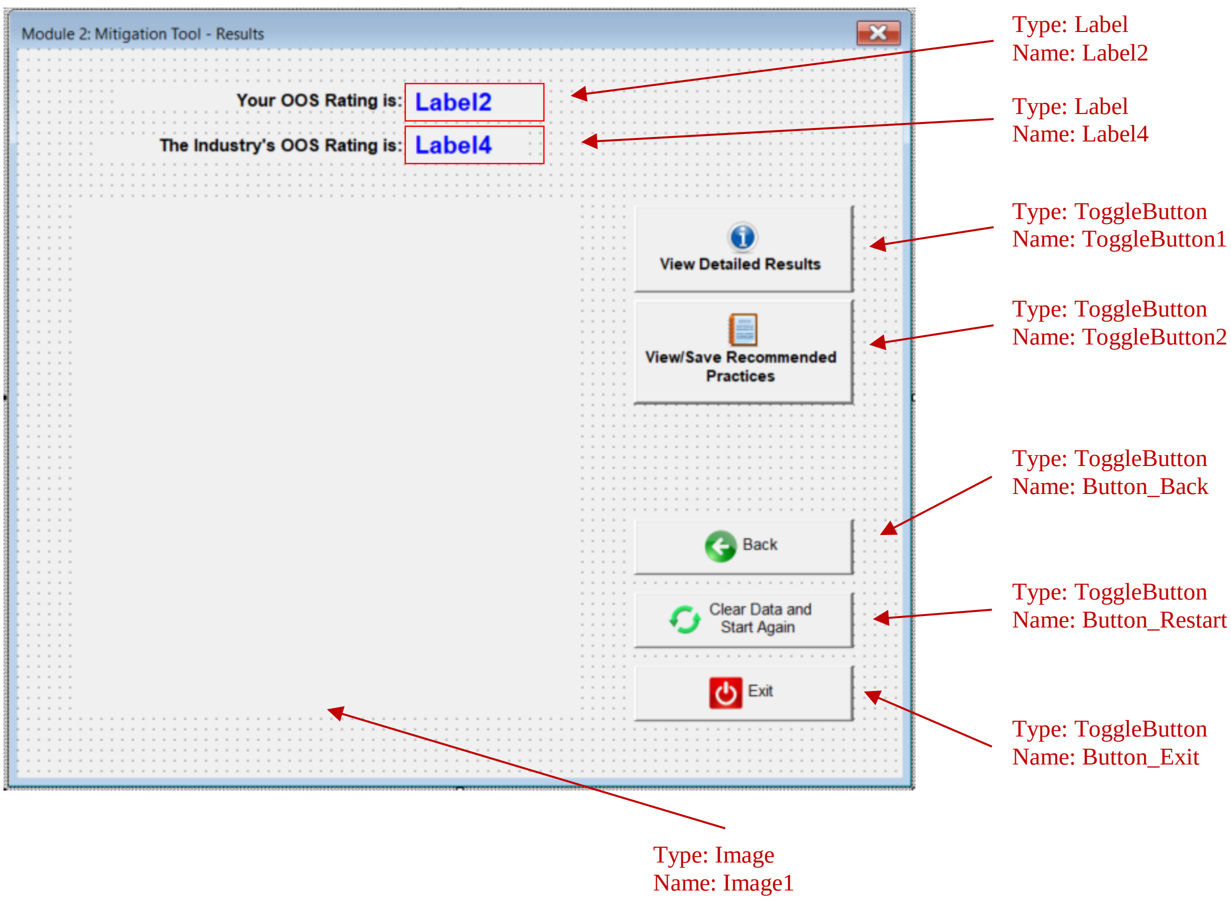
```
        k = k - 1
    Else
        Set text3 = Controls.Add("Forms.TextBox.1")
        With text3
            .Name = "impacts" & k
            .Top = 10 * k * 2 + 380
            .Left = 533
            .BackColor = &H80000005
            .Width = 35
            .Height = 15
            .BackStyle = 1
            .BorderStyle = 0
            .TextAlign = 1
            .Text = ws.Cells(knew + 1, 10).Value
        End With
    End If
    knew = knew + 1
Next k


'set the vertical scroll bars
Me.ScrollBars = fmScrollBarsVertical
'Me.ScrollHeight = Me.InsideHeight * 2
Me.ScrollHeight = 10 * j * 2 + 430


End Sub


Private Sub button_compute_Click()

Set ws = Worksheets("Database")

'coppy the likelihood values inputted by the user to the database
```

```
For k = 1 To oos_count

    'this gets the value of the last item added to the controls
(form2.Controls.Count - 1)
    ws.Cells(k + 1, 11).Value =
form2.Controls.Item(form2.Controls.Count - oos_count - oos_count + k -
1).Value
Next k

'coppy the impact values inputted by the user to the database
For k = 1 To oos_count
    'this gets the value of the last item added to the controls
(form2.Controls.Count - 1)
    ws.Cells(k + 1, 10).Value =
form2.Controls.Item(form2.Controls.Count - oos_count + k - 1).Value
Next k

If ws.Cells(2, 19) = 1 Then
MsgBox "Error: One or more fields are empty. Please make sure to fill
all the required fields"
'form2.button_compute.Value = False
End If

If ws.Cells(2, 20) = 1 Then
MsgBox "Error: Please make sure all required fields have NUMERICAL
values"
'form2.button_compute.Value = False
End If

If ws.Cells(2, 21) = 1 Then
MsgBox "Error: Please make sure all required fields have values
between 1 and 5"
'form2.button_compute.Value = False
End If

If ws.Cells(2, 19) = 0 And ws.Cells(2, 20) = 0 And ws.Cells(2, 21) = 0
Then
```

```
Unload Me
form3.Show
End If

End Sub
```

For the Userform named “form3”:

Userform Information:



VBA Code Used in the Userform:

```
Private Sub button_back_Click()
Unload Me
form2.Show
End Sub
```

```
Private Sub button_exit_Click()

'a message box before exiting to prevent accidental exit
Dim msg, button, title, response
  msg = "Are you sure you want to exit?"
  button = vbYesNo + vbDefaultButton2
  title = "Confirm Exit"

  response = MsgBox(msg, button, title)
  If response = vbYes Then
    Unload Me
    Call clear_data
  Else
    Exit Sub
    'Unload form0
    'form0.Show
  End If

Worksheets("Database").Range("E2:K89").ClearContents
Unload Me

End Sub

Private Sub Button_Restart_Click()
Call clear_data
Unload Me
Dashboard.Show
End Sub

Private Sub CommandButton1_Click()

'This FF variable is the page number at which the file will end
exporting at
Dim FF As Long
```

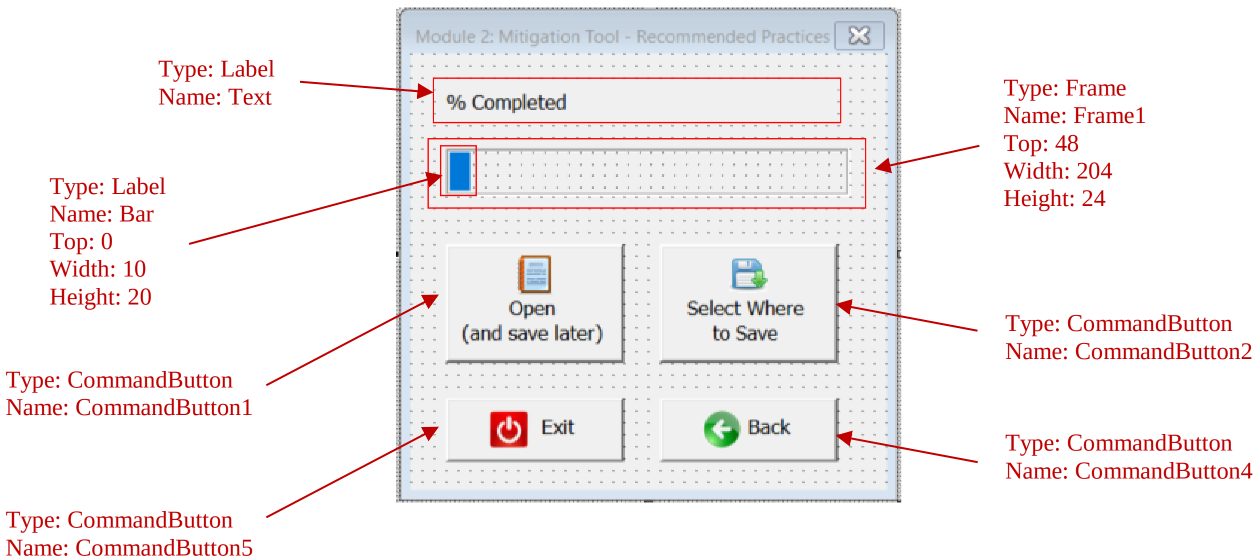
```
If Worksheets("Detailed_Results").Cells(50, 1).Value = "" Then
    FF = 1
    Else
        If Worksheets("Detailed_Results").Cells(97, 1).Value = "" Then
            FF = 2
            Else
                FF = 3
        End If
End If

Sheets("Detailed_Results").Visible = True
Worksheets("Detailed_Results").ExportAsFixedFormat _
    Type:=xlTypePDF, _
    FileName:="Details of the OOS Rating Score", _
    Quality:=xlQualityStandard, _
    IncludeDocProperties:=False, _
    IgnorePrintAreas:=False, _
    From:=1, _
    To:=FF, _
    OpenAfterPublish:=True
Sheets("Detailed_Results").Visible = False
End Sub




Private Sub CommandButton2_Click()

Unload Me
Best_Practices_Loading.Show

End Sub

Private Sub UserForm_Initialize()
```

```
Worksheets("Database").Activate
Worksheets("Database").Range("AG35").Activate

'show the score in the label
'form3.Label2.Caption = Sheets("Database").Cells(2, 13).Value
form3.Label2.Caption = Format(Sheets("Database").Cells(2, 13).Value,
"0.00")
form3.Label4.Caption = Format(Sheets("Database").Cells(2, 16).Value,
"0.00")
'Set CurrentChart = Sheets("Database").ChartObjects(1).Chart
    'Fname = ThisWorkbook.Path & "\temp.gif"
    'CurrentChart.Export Filename:=Fname, FilterName:="GIF"
    'Image1.Picture = LoadPicture(Fname)

Set chtObj = Sheets("Database").ChartObjects.Add(100, 30, 400, 250)
chtObj.Name = "TemporaryPictureChart"

'resize chart to picture size
chtObj.Width = Sheets("Database").Shapes("Group 33").Width
chtObj.Height = Sheets("Database").Shapes("Group 33").Height

Sheets("Database").Shapes.Range(Array("Group 33")).Select
Selection.Copy

Sheets("Database").ChartObjects("TemporaryPictureChart").Activate
'ActiveChart.Paste
ActiveChart.Pictures.Paste.Select

Fname = ThisWorkbook.Path & "\temp1.jpg"
ActiveChart.Export FileName:=Fname, FilterName:="jpg"

chtObj.Delete
Image1.Picture = LoadPicture(Fname)
```

```
Worksheets("Main").Activate
Worksheets("Main").Range("A1").Activate
Kill Fname


End Sub
```

For the Userform named "Best_Practices_Loading":

Userform Information:



VBA Code Used in the Userform:

```
Private Sub CommandButton1_Click()


ThisWorkbook.FollowHyperlink (Application.ThisWorkbook.Path &
"\Supporting Files\Best Practices\Final Best Practices\Best
Practices.docx")


End Sub


Private Sub CommandButton2_Click()
```

```
    Dim varResult As Variant
    'displays the save file dialog
    varResult = Application.GetSaveAsFilename(FileFilter:= _
    "Word Document (*.docx), *.xlsx" _
    , title:="Select Where you Want to Save the Best Practices (please
type the desired file name as well)", _
    InitialFileName:=Application.ThisWorkbook.Path)
    'checks to make sure the user hasn't canceled the dialog
    If varResult <> False Then
    FileCopy Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\Final Best Practices\Best Practices.docx", varResult
    MsgBox "File Saved"
    End If

End Sub

Private Sub CommandButton4_Click()

Unload Me
form3.Show

End Sub

Private Sub CommandButton5_Click()

'a message box before exiting to prevent accidental exit
Dim msg, button, title, response
  msg = "Are you sure you want to exit?"
  button = vbYesNo + vbDefaultButton2
  title = "Confirm Exit"

  response = MsgBox(msg, button, title)
  If response = vbYes Then
    Unload Me
```

```
    Call clear_data
  Else
    Exit Sub
    'Unload form0
    'form0.Show
  End If

End Sub

Private Sub Text_Click()

End Sub

Private Sub UserForm_Activate()

Best_Practices_Loading.Text.Caption = "Loading Recommended Practices:
" & Worksheets("Best_Practices").Range("AP3").Value & "%"
Best_Practices_Loading.Bar.Width =
Worksheets("Best_Practices").Range("AP3").Value * 2

'##################################### FETCH
########################################
'######################################################################
###############

    'delete all files in the (Fetched Documents) and (Final Best
Practices) Folders
    'If these folders were already empty, the "KILL" function will
yield a bug
    'So we copy an empty "temporary" file in each of these folders
just to make sure they are not empty
    'Then we use the KILL function to clear the contents of those
folders
    FileCopy Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\temporary.docx", Application.ThisWorkbook.Path &
"\Supporting Files\Best Practices\Final Best Practices\temporary.docx"
```

```
    FileCopy Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\temporary.docx", Application.ThisWorkbook.Path &
"\Supporting Files\Best Practices\Fetched Documents\temporary.docx"


    Kill Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\Final Best Practices\*.*"
    Kill Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\Fetched Documents\*.*"




'Copy the relevent best practices from their locations to the "Fetched
Documents" folder in preparation for their merging
Dim Fe As Long
Dim Fee As Long
Fee = 1
Dim FileName As String
Dim Loading As Integer


'Stage 1 Documents
If Worksheets("Database2").Cells(10, 2).Value = 1 Then
    For Fe = 1 To 21
        If Worksheets("Best_Practices").Cells(Fe + 2, 32).Value = 1
Then
            Fee = Fe
            FileName = Fee & ".docx"
            FileCopy Application.ThisWorkbook.Path & "\Supporting
Files\Best Practices\Stage 1\" & FileName,
Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\Fetched Documents\" & FileName
            'FileCopy Application.ThisWorkbook.Path & "\Supporting
Files\Best Practices\Fetched Documents\" & FileName,
Application.ThisWorkbook.Path & "\Best Practices\" & FileName
        End If
    Next Fe
    Loading = 10
    Worksheets("Best_Practices").Range("AP3").Value = Loading
```

```
    Best_Practices_Loading.Text.Caption = "Loading Recommended
Practices:  " & Worksheets("Best_Practices").Range("AP3").Value & "%"
    Best_Practices_Loading.Bar.Width =
Worksheets("Best_Practices").Range("AP3").Value * 2
End If

'Stage 2 Documents
If Worksheets("Database2").Cells(10, 2).Value = 2 Then
    For Fe = 1 To 21
        If Worksheets("Best_Practices").Cells(Fe + 2, 32).Value = 1
Then
            Fee = Fe
            FileName = Fee & ".docx"
            FileCopy Application.ThisWorkbook.Path & "\Supporting
Files\Best Practices\Stage 2\" & FileName,
Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\Fetched Documents\" & FileName

        End If
    Next Fe
    Loading = 10
    Worksheets("Best_Practices").Range("AP3").Value = Loading
    Best_Practices_Loading.Text.Caption = "Loading Recommended
Practices:  " & Worksheets("Best_Practices").Range("AP3").Value & "%"
    Best_Practices_Loading.Bar.Width =
Worksheets("Best_Practices").Range("AP3").Value * 2
End If

'Stage 3 Documents
If Worksheets("Database2").Cells(10, 2).Value = 3 Then
    For Fe = 1 To 21
        If Worksheets("Best_Practices").Cells(Fe + 2, 32).Value = 1
Then
            Fee = Fe
            FileName = Fee & ".docx"
            FileCopy Application.ThisWorkbook.Path & "\Supporting
Files\Best Practices\Stage 3\" & FileName,
```

```
Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\Fetched Documents\" & FileName

        End If

    Next Fe

    Loading = 10

    Worksheets("Best_Practices").Range("AP3").Value = Loading

    Best_Practices_Loading.Text.Caption = "Loading Recommended
Practices:  " & Worksheets("Best_Practices").Range("AP3").Value & "%"

    Best_Practices_Loading.Bar.Width =
Worksheets("Best_Practices").Range("AP3").Value * 2

End If


'Stage 4 Documents

If Worksheets("Database2").Cells(10, 2).Value = 4 Then

    For Fe = 1 To 21

        If Worksheets("Best_Practices").Cells(Fe + 2, 32).Value = 1
Then

            Fee = Fe

            FileName = Fee & ".docx"

            FileCopy Application.ThisWorkbook.Path & "\Supporting
Files\Best Practices\Stage 4\" & FileName,
Application.ThisWorkbook.Path & "\Supporting Files\Best
Practices\Fetched Documents\" & FileName

        End If

    Next Fe

    Loading = 10

    Worksheets("Best_Practices").Range("AP3").Value = Loading

    Best_Practices_Loading.Text.Caption = "Loading Recommended
Practices:  " & Worksheets("Best_Practices").Range("AP3").Value & "%"

    Best_Practices_Loading.Bar.Width =
Worksheets("Best_Practices").Range("AP3").Value * 2

End If



'#################################### MERGE
########################################

'######################################################################
###############
```

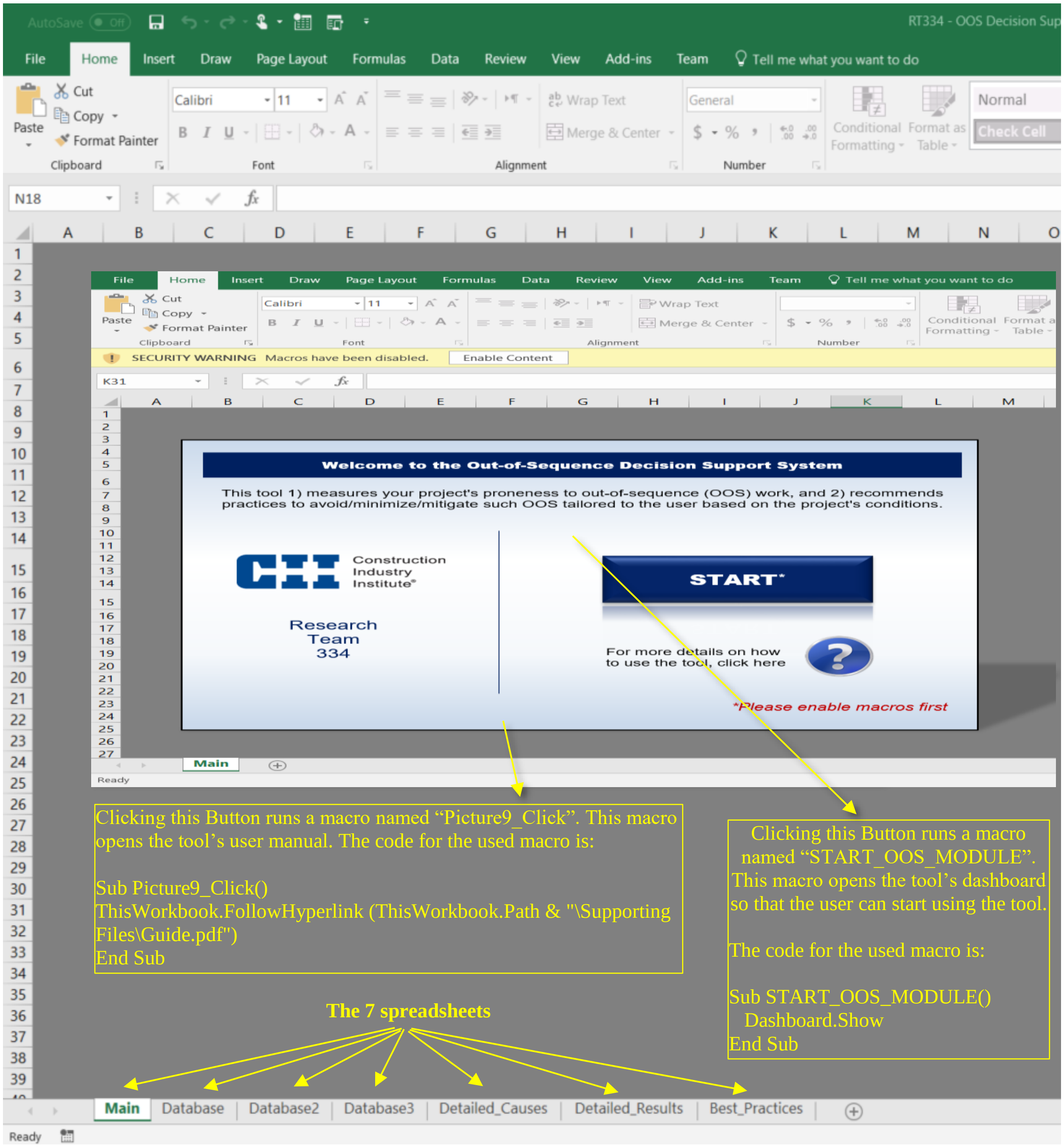
```
On Error GoTo Tryagain

Dim AAA As Long
Worksheets("Best_Practices").Range("AN3:AN27").Clear

    AAA = 3
    For NBP = 3 To 23
            If Worksheets("Best_Practices").Range("AF" & NBP).Value =
1 Then
                Worksheets("Best_Practices").Range("AN" & AAA).Value =
Worksheets("Best_Practices").Range("S" & NBP).Value
                AAA = AAA + 1
            End If
    Next

    Folderpath = Application.ThisWorkbook.Path & "\Supporting
Files\Best Practices\Fetched Documents"
    Set fso = CreateObject("Scripting.FileSystemObject")
    NoOfFiles = fso.GetFolder(Folderpath).Files.Count

    MergeFileName = "Best Practices.docx"
    MergeFolder = Application.ThisWorkbook.Path & "\Supporting
Files\Best Practices\Final Best Practices"

    Set objWord = CreateObject("Word.Application")

   Set objDoc = objWord.Documents.Add

   objWord.Visible = True

   Set objSelection = objWord.Selection
   objDoc.SaveAs (MergeFolder & "\" & MergeFileName)
   Loading = 20
    Worksheets("Best_Practices").Range("AP3").Value = Loading
```

```
    Best_Practices_Loading.Text.Caption = "Loading Recommended 
Practices:  " & Worksheets("Best_Practices").Range("AP3").Value & "%"
    Best_Practices_Loading.Bar.Width = 
Worksheets("Best_Practices").Range("AP3").Value * 2


    Set objTempWord = CreateObject("Word.Application")


    For i = 1 To NoOfFiles
            Set tempDoc = objWord.Documents.Open(Folderpath & "\" & 
Worksheets("Best_Practices").Range("AN" & i + 2).Value & ".docx")
            Set objTempSelection = objTempWord.Selection
            tempDoc.Range.Select
            tempDoc.Range.Copy
            tempDoc.Close
            Loading = 20 + i / NoOfFiles * 70
    Worksheets("Best_Practices").Range("AP3").Value = Loading
    Best_Practices_Loading.Text.Caption = "Loading Recommended 
Practices:  " & Worksheets("Best_Practices").Range("AP3").Value & "%"
    Best_Practices_Loading.Bar.Width = 
Worksheets("Best_Practices").Range("AP3").Value * 2


    'clear the clipboard
    Application.CutCopyMode = False


    Next



    objDoc.Save
    objDoc.Close
    Loading = 90
    Application.ScreenUpdating = True
    Worksheets("Best_Practices").Range("AN3:AN27").Clear
    Loading = 100
    Worksheets("Best_Practices").Range("AP3").Value = Loading
    Best_Practices_Loading.Text.Caption = "Recommended Practices: 
Complete"
```

```
    Best_Practices_Loading.Bar.Width =
Worksheets("Best_Practices").Range("AP3").Value * 2

    Best_Practices_Loading.Bar.BackColor = &HC000&


    'MsgBox "Completed...Merge File is saved at " & MergeFolder & "\"
& MergeFileName

    Worksheets("Best_Practices").Range("AP3").Value = 0



Exit Sub

'**********************

'ERROR HANDLING SECTION

'**********************

Tryagain:

    Unload Best_Practices_Loading

    MsgBox "Warning:  " & Err.Number & vbNewLine & "Please close all
Microsoft Word documents then try again by clicking (View/Save Best
Practices)." & vbNewLine & "Your progress is NOT lost."

    form3.Show



End Sub
```

<u>The Spreadsheets that Are Used in the OOS Decision Support Tool</u>

The OOS Decision Support Tool is formed of 7 spreadsheets as shown in the following page. However, 6 of them are hidden and only the “Main” one is shown. The user does not need to see the other ones. They are only used by the OOS Decision Support Tool while doing its calculations. The following picture just shows them un-hidden.



It is not possible to show the information of the spreadsheets in this appendix due to size limitation. However, users or researchers who are interested in knowing the content of such spreadsheets can download the OOS Decision Support Tool and unhide them.

Appendix E:

Used Equations and Data for the Developed System Dynamics Model

Levels (Stocks):

- Actual Progress at t = INTEG ("Actual Weekly Progress % (Project)", 0)
- Actual Cumulative Weekly Staffing (Project) = INTEG ("Actual Weekly Staffing (Project)", 0)
- Initial Completion Backlog = INTEG (-Initial Completion Rate, Initial Work Units)
- Planned Cumulative Weekly Staffing (Project) = INTEG ("Planned Weekly Staffing (Project)", 0)
- Planned Progress at t = INTEG ("Planned Weekly Progress % (Project)",0)
- QA Baklog= INTEG (Initial Completion Rate+Rework Completion Rate-Approval Rate-Rework Discovery Rate, 0)
- Rework Backlog = INTEG (Rework Discovery Rate+Undiscovered Rework Discovery Rate-Rework Completion Rate, 0)
- Rework Due to Low Quality = INTEG (Rework Discovery Rate, 0)
- Rework Due To Mistakes of QA Staff = INTEG (Errors Rate,0)
- Total Rework Value = INTEG (Errors Rate+Rework Discovery Rate, 0)
- Simulated Cumulative Staffing= INTEG (Simulated Staffing, 0)
- Simulated Staffing= INTEG (Diff,4.173)
- Undiscovered Rework = INTEG (Errors Rate-Undiscovered Rework Discovery Rate,0)
- Work Released= INTEG (Approval Rate-Undiscovered Rework Discovery Rate, 0)

Rates (Flows):

- Approval Rate = MAX(QA Rate-Rework Discovery Rate, 0)
- Errors Rate = Approval Rate*(1-QA Effectiveness Factor)
- Initial Completion Rate = MAX(MIN(IC Process Rate , IC Resource Rate), 0)
- Rework Completion Rate = MAX(MIN(RW Process Rate, RW Resource Rate), 0)
- Rework Discovery Rate = MAX(Fraction Discovered to Require Change*QA Rate, 0)
- Undiscovered Rework Discovery Rate =MAX(MIN(Undiscovered Rework/Duration of Discovering Rework, Undiscovered Rework),0)

Auxiliary Variables:

- (Simulated) Rework % Due to Low Quality = ZIDZ(Rework Due to Low Quality, QA Baklog+Work Released)*100
- (Simulated) Rework % Due To Mistakes of QA Staff = ZIDZ(Rework Due To Mistakes of QA Staff, QA Baklog+Work Released)*100
- Actual Weekly Staffing at t-1= DELAY FIXED("Actual Weekly Staffing (Project)", 1 , 0)
- All Backlogs = Initial Completion Backlog+QA Baklog+Undiscovered Rework+Work Released+Rework Backlog
- Check Points = PULSE TRAIN(1, 1 , N , 307)
- Cumulative Earned Cost (Model) = Work Released
- Cumulative Progress % (Model) = Work Released/All Backlogs*100
- Cumulative Progress at t-5 = DELAY FIXED("Cumulative Progress % (Model)", 5 , 0)
- Difference = "Actual Weekly Staffing (Project)"-"Actual Weekly Staffing at t-1"
- Fraction Discovered to Require Change = 1-((1-(Impact of OOS on Quality*"Percentage of OOS Work ($ Value)"))*Planned IC staff quality of work)
- Fraction of IC Labor Required = ZIDZ(Initial Completion Backlog, "IC+QC+RW Backlogs")
- Fraction of QA Labor Required = ZIDZ(QA Baklog, "IC+QC+RW Backlogs"*QA Progress Rate Factor)
- Fraction of RW Labor Required = ZIDZ(Rework Backlog,"IC+QC+RW Backlogs")
- IC Process Rate = Initial Completion Backlog/"Min. IC Duration"
- IC Resource Rate = IC Staff*Progress Rate
- IC Staff = Fraction of IC Labor Required*Simulated Staffing
- IC+QC+RW Backlogs = Initial Completion Backlog+QA Baklog+Rework Backlog
- Initial Work Units = "Max. Planned Cumulative Earned Cost (Project)"
- Percentage of OOS Work ($ Value) = "$ Value of OOS Activities"/Total Project Budgeted Cost*100
- Phase 1 PR = IF THEN ELSE((1-(OOSDR on Ph1*"Percentage of OOS Work ($ Value)"))*Ph1 < 0 , 0.1 , (1-(OOSDR on Ph1*"Percentage of OOS Work ($ Value)"))*Ph1)

- Phase 2 PR = IF THEN ELSE((1-(OOSDR on Ph2*"Percentage of OOS Work ($ Value)"))*Ph2 < 0 , 0.1 , (1-(OOSDR on Ph2*"Percentage of OOS Work ($ Value)"))*Ph2)

- Phase 3 PR = IF THEN ELSE((1-(OOSDR on Ph3*"Percentage of OOS Work ($ Value)"))*Ph3 < 0 , 0.1 , (1-(OOSDR on Ph3*"Percentage of OOS Work ($ Value)"))*Ph3)

- Phase 4 PR = IF THEN ELSE((1-(OOSDR on Ph4*"Percentage of OOS Work ($ Value)"))*Ph4 < 0 , 0.1 , (1-(OOSDR on Ph4*"Percentage of OOS Work ($ Value)"))*Ph4)

- Phase 5 PR = IF THEN ELSE((1-(OOSDR on Ph5*"Percentage of OOS Work ($ Value)"))*Ph5 < 0 , 0.1 , (1-(OOSDR on Ph5*"Percentage of OOS Work ($ Value)"))*Ph5)

- Phase 6 PR = IF THEN ELSE((1-(OOSDR on Ph6*"Percentage of OOS Work ($ Value)"))*Ph6 < 0 , 0.1 , (1-(OOSDR on Ph6*"Percentage of OOS Work ($ Value)"))*Ph6)

- Phase Production Rate Differential = IF THEN ELSE("Cumulative Progress % (Model)"<=0.242, Phase 1 PR , IF THEN ELSE("Cumulative Progress % (Model)"<=13.13, Phase 2 PR, IF THEN ELSE("Cumulative Progress % (Model)"<=23.1, Phase 3 PR, IF THEN ELSE("Cumulative Progress % (Model)"<=25.33, Phase 4 PR, IF THEN ELSE("Cumulative Progress % (Model)" <=79.5, Phase 5 PR, Phase 6 PR)))))

- Progress Rate = "Avg. Progress Rate"*Phase Production Rate Differential

- QA Effectiveness Factor = (1 - ("Percentage of OOS Work ($ Value)"*Impact of OOS on QA Effectivenss)) * Planned QA Effectiveness Factor

- QA Process Rate = QA Baklog/"Min. QA Duration"

- QA Rate = MIN(QA Process Rate, QA Resource Rate)

- QA Resource Rate = QA Progress Rate Factor*QA Staff*Progress Rate

- QA Staff = Fraction of QA Labor Required*Simulated Staffing

- RW Process Rate = Rework Backlog/"Min. RW Duration"

- RW Resource Rate = RW Staff*Progress Rate

- RW Staff = Fraction of RW Labor Required*Simulated Staffing

- Staffing at t-1= DELAY FIXED (Simulated Staffing, 1 , 0)

- Total Rework % = "(Simulated) Rework % Due to Low Quality"+"(Simulated) Rework % Due To Mistakes of QA Staff"

Variables that are Present Only in Method 1 of the Staffing Module:

- Actual Weeks Remaining = (Approved Project End Date-Time)*Check Points

- Avg. Production Rate in Previous N Steps = Work Released in Previous N Steps/N

- Diff = IF THEN ELSE(Time<Start of This Module, Difference , MIN(("Staffing at t-1"*"Fraction Staffing Increase/Decrease Required") - "Staffing at t-1", "Max. Available Man Hrs"-"Staffing at t-1")*Check Points)

- Phase-related Staffing Requirement Factor = IF THEN ELSE("Cumulative Progress % (Model)"<=0.242, "Cor. Ph1" , IF THEN ELSE("Cumulative Progress % (Model)"<=13.13, "Cor. Ph2" , IF THEN ELSE("Cumulative Progress % (Model)"<=23.1, "Cor. Ph3" , IF THEN ELSE("Cumulative Progress % (Model)"<=25.33, "Cor. Ph4" , IF THEN ELSE("Cumulative Progress % (Model)"<=79.5, "Cor. Ph5" , "Cor. Ph6")))))

- Forecasted End Date = (Time+"Forecasted Weeks Remaining (Based on last N steps)")*Check Points

- Forecasted Weeks Remaining (Based on last N steps) = IF THEN ELSE(Time<=Start of This Module, 280-Time , ZIDZ(Units Left,"Avg. Production Rate in Previous N Steps"))*Check Points

- Fraction Staffing Increase/Decrease Required = Schedule Performance*"Phase-related Staffing Requirement Factor"

- Schedule Performance = ZIDZ("Forecasted Weeks Remaining (Based on last N steps)", Actual Weeks Remaining)

- Units Left = "Max. Planned Cumulative Earned Cost (Project)"-Work Released

- Work Released in Previous N Steps = IF THEN ELSE(N=5, Work Released-"WR at t-5", Work Released-"WR at t-4")*Check Points

- WR at t-4 = DELAY FIXED(Work Released, 4 , 0)

- WR at t-5 = DELAY FIXED(Work Released, 5 , 0)

Variables that are Present Only in Method 2 of the Staffing Module:

- Forecasted Progress at t+5 = MIN(("Cumulative Progress % (Model)"+(N*"Slope of Simulated Progress (A)")),100)*Check Points

- Progress Factor = IF THEN ELSE("Approved Progress at t+5">99 , IF THEN ELSE("Forecasted Progress at t+5">99, 0.1 , ZIDZ("Approved Progress at t+5", "Forecasted Progress at t+5")) , ZIDZ("Approved Progress at t+5", "Forecasted Progress at t+5"))

- Slope Factor = IF THEN ELSE("Slope of Approved Progress (B)"<0.1, 1 , ZIDZ("Slope of Approved Progress (B)", "Slope of Simulated Progress (A)"))

- Slope of Approved Progress (B) = ("Approved Progress at t+5"-Planned Progress at t)/N*Check Points

- Slope of Simulated Progress (A) = ("Cumulative Progress % (Model)"-"Cumulative Progress at t-5")/N*Check Points

- Staffing Requirement Factor = IF THEN ELSE("Cumulative Progress % (Model)">95, IF THEN ELSE(Slope Factor>1, IF THEN ELSE(Progress Factor<=1, Progress Factor , (Progress Factor*0.5)+(Slope Factor*0.5)) , (Progress Factor*0.5)+(Slope Factor*0.5)) , IF THEN ELSE("Cumulative Progress % (Model)">79.5 , IF THEN ELSE(Slope Factor<1, IF THEN ELSE(Progress Factor>1 , Progress Factor , (Progress Factor*0.5)+(Slope Factor*0.5)) , (Progress Factor*0.5)+(Slope Factor*0.5)) , (Progress Factor*0.5)+(Slope Factor*0.5)))

- Diff = IF THEN ELSE(Time<Start of This Module, Difference , MIN(("Staffing at t-1"*Staffing Requirement Factor) - "Staffing at t-1", "Max. Available Man Hrs"-"Staffing at t-1")*Check Points)

Constants:

- Cor. Ph1 = 1
- Cor. Ph2 = 0.6041
- Cor. Ph3 = 0.2779
- Cor. Ph4 = 0.1121
- Cor. Ph5 = 0.918
- Cor. Ph6 = 1
- Ph1 = 4.858
- Ph2 = 1.136
- Ph3 = 0.5631
- Ph4 = 0.416
- Ph5 = 0.976
- Ph6 = 0.8553
- OOSDR on Ph1 = 0
- OOSDR on Ph2 = 0

- OOSDR on Ph3 = 0.9518
- OOSDR on Ph4 = 0.4634
- OOSDR on Ph5 = 0.0305
- OOSDR on Ph6 = -0.1482
- Avg. Progress Rate = 5.5
- N = 5
- Start of This Module = 30
- Duration of Discovering Rework = 1
- Impact of OOS on QA Effectivenss = 0.00527
- Impact of OOS on Quality = 0.02895
- "Max. Planned Cumulative Earned Cost (Project)" = 48625.4
- "Min. IC Duration" = 1
- "Min. QA Duration" = 1
- "Min. RW Duration" = 1
- Planned QA Effectiveness Factor = 0.999
- Planned IC staff quality of work = 0.99
- QA Progress Rate Factor = 5
- Total Project Budgeted Cost = 48625.4

Data Variables:

Time	Actual Weekly Progress % (Project)	Actual Weekly Staffing (Project)	Planned Weekly Progress % (Project)	Planned Weekly Staffing (Project)
0	0	4.173	0	4.17
1	0.01018	14.713	0.01018	14.31
2	0.02438	14.713	0.02438	14.31
3	0.05813	14.713	0.0556	14.31
4	0.0643	20.493	0.06472	19.49
5	0.08688	20.108	0.0873	19.11
6	0.0933	28.086	0.09365	28.09
7	0.07464	26.42	0.07492	26.42
8	0.12339	21.361	0.12382	21.37
9	0.13621	17.301	0.13665	17.31
10	0.09925	25.453	0.09955	25.46
11	0.13463	30.543	0.13499	30.55
12	0.16155	34.826	0.16199	34.83
13	0.16857	39.109	0.17312	39.12
14	0.17354	37.952	0.18426	37.96
15	0.17313	36.796	0.18179	36.8
16	0.17067	33.223	0.17933	33.23
17	0.14994	51.806	0.15647	51.81
18	0.19458	51.768	0.19502	51.78
19	0.19449	51.691	0.19493	51.7
20	0.1943	51.691	0.19474	51.7
21	0.1943	38.258	0.19474	38.26
22	0.14863	42.205	0.14899	42.21
23	0.16809	47.9224	0.16852	43.16
24	0.17078	40.116	0.17099	35.59
25	0.14773	36.4432	0.14815	32.49
26	0.13919	39.2226	0.13961	34.79
27	0.14623	34.9572	0.14666	31.14
28	0.1263	40.8988	0.12871	38.09
29	0.1245	55.8025	0.12896	52.98
30	0.16649	40.1084	0.16691	41.11
31	0.12656	52.8674	0.13315	56.63
32	0.15391	150.59	0.15844	163.87
33	0.18187	58.2288	0.1823	93
34	0.18379	155.863	0.18421	167.88
35	0.18519	47.3657	0.18562	86.05
36	0.15161	117.116	0.1726	147.53
37	0.13522	26.7165	0.13564	77.83
38	0.1371	26.4411	0.13752	80.88
39	0.13688	21.8885	0.1373	52.75
40	0.11373	37.2558	0.11408	48.04
41	0.15827	27.758	0.15869	39.47
42	0.13935	18.629	0.13977	32.57
43	0.12031	18.543	0.12073	32.57
44	0.11208	18.787	0.12073	32.56
45	0.11205	10.5386	0.1207	21.12
46	0.05055	21.6385	0.06105	34.76
47	0.12491	22.6215	0.12535	35.44
48	0.11422	24.305	0.12289	37.02
49	0.10686	23.1712	0.11758	35.98
50	0.11559	19.3205	0.11607	31.07
51	0.08787	22.9016	0.09654	35.86
52	0.10406	29.9161	0.11693	41.03
53	0.12574	58.3899	0.12628	62.74
54	0.11578	33.9381	0.12871	44.22
55	0.11099	33.9257	0.12598	44.19

Time	Actual Weekly Progress % (Project)	Actual Weekly Staffing (Project)	Planned Weekly Progress % (Project)	Planned Weekly Staffing (Project)
56	0.11383	28.2224	0.12676	36.69
57	0.08747	48.6962	0.09608	55.54
58	0.15525	45.623	0.15584	53.51
59	0.12444	37.7657	0.14559	45.52
60	0.10963	44.1747	0.11629	52
61	0.13472	31.4402	0.13737	42.49
62	0.09788	37.5352	0.10998	45.07
63	0.11213	50.0092	0.12291	54.92
64	0.13859	64.1953	0.1432	67.65
65	0.13388	53.2576	0.14152	59.29
66	0.13861	57.4645	0.15472	60.77
67	0.12956	48.5795	0.15744	54.17
68	0.12915	80.8778	0.14888	71.41
69	0.16211	68.4882	0.19181	61.71
70	0.1612	81.8602	0.17032	72.32
71	0.15016	67.4773	0.1587	61.31
72	0.11995	52.8624	0.12689	45.94
73	0.13551	126.936	0.14329	100.33
74	0.15913	76.8436	0.16816	62.36
75	0.16523	51.8831	0.17458	42.93
76	0.1584	52.6896	0.1674	43.11
77	0.15785	175.279	0.16683	136.46
78	0.18239	38.572	0.19267	29.38
79	0.15493	53.9843	0.16355	40.98
80	0.1507	31.6214	0.15911	24.49
81	0.14929	27.9198	0.1577	21.7
82	0.16549	43.769	0.17488	33.23
83	0.17524	61.3162	0.18514	47.54
84	0.18053	59.1491	0.19114	45.81
85	0.16967	72.6078	0.17917	55.54
86	0.18151	77.0528	0.19157	59.33
87	0.1825	85.3812	0.19262	65.48
88	0.19995	73.7199	0.21101	56.63
89	0.17707	71.4906	0.18698	55.07
90	0.16652	78.5907	0.17584	60.2
91	0.18106	83.1754	0.19095	64.13
92	0.18512	49.8835	0.19525	38.08
93	0.10734	55.7108	0.11323	42.54
94	0.12238	47.0562	0.12909	35.87
95	0.10141	35.9731	0.10703	27.19
96	0.07849	62.1823	0.08286	47.62
97	0.14024	91.7994	0.14796	70.34
98	0.20054	88.027	0.21154	67.34
99	0.19414	86.7163	0.20489	66.73
100	0.18621	87.4701	0.20695	67.23
101	0.20161	77.7568	0.213	59.47
102	0.18373	51.6498	0.19415	39.45
103	0.12532	72.9328	0.13254	56.4
104	0.16923	70.9682	0.17895	54.27
105	0.16332	46.9099	0.17269	36.26
106	0.10883	77.9556	0.11497	60.05
107	0.17979	95.9491	0.18983	74.2
108	0.2106	69.3876	0.22249	53.39
109	0.15465	77.3362	0.16345	59.93
110	0.1721	76.8477	0.18196	58.99
111	0.16801	71.3891	0.17773	54.99

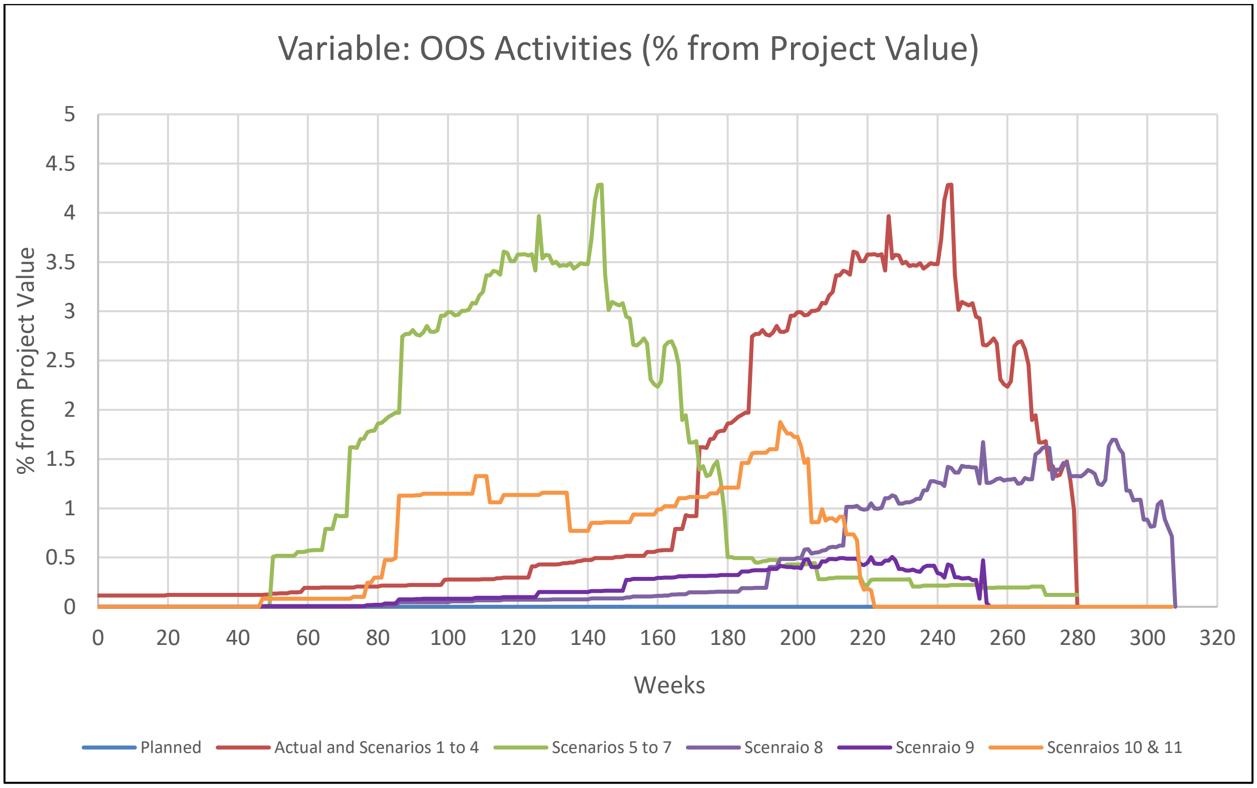
Time	Actual Weekly Progress % (Project)	Actual Weekly Staffing (Project)	Planned Weekly Progress % (Project)	Planned Weekly Staffing (Project)
112	0.16399	69.2641	0.17368	53.81
113	0.16223	70.4834	0.17187	54.21
114	0.16224	51.7555	0.17198	40.1
115	0.12349	54.0594	0.13115	41.92
116	0.12553	68.2293	0.13355	52.94
117	0.15624	52.3605	0.16626	40.52
118	0.12466	62.4507	0.13271	48.6
119	0.14939	69.6516	0.15905	54.07
120	0.16167	73.2052	0.17208	57.16
121	0.1691	76.7223	0.17991	59.29
122	0.17493	74.7238	0.18606	57.84
123	0.17265	73.0686	0.18367	56.55
124	0.16809	69.775	0.17905	54.45
125	0.16099	75.3267	0.17183	58.58
126	0.17276	75.8897	0.18434	59.03
127	0.17299	75.7454	0.18458	58.93
128	0.17013	75.1533	0.18162	58.58
129	0.16536	72.4193	0.1771	57.39
130	0.16037	74.1529	0.17257	59.07
131	0.16439	66.8788	0.17715	53.13
132	0.14281	66.8847	0.1538	53.23
133	0.13694	68.4357	0.14789	54.65
134	0.14064	80.751	0.15201	64.42
135	0.16977	84.0991	0.18385	67.61
136	0.17073	76.6977	0.18508	61.48
137	0.16079	76.3256	0.17473	61.74
138	0.16314	81.1996	0.17794	66.09
139	0.16829	88.1542	0.18404	71.06
140	0.17627	83.0219	0.19288	67.68
141	0.17127	79.6973	0.18819	64.58
142	0.16293	54.015	0.17891	43.77
143	0.11224	58.2415	0.12363	46.95
144	0.11628	50.5956	0.1274	40.91
145	0.09703	56.7619	0.1056	46.33
146	0.11473	31.7783	0.12508	26.1
147	0.06774	87.1172	0.07406	71.66
148	0.18401	90.4885	0.20144	74.91
149	0.19145	88.1039	0.21019	72.81
150	0.18401	83.817	0.2023	69.88
151	0.16957	84.4893	0.18776	70.15
152	0.18746	80.3099	0.20673	67.6
153	0.17181	80.5357	0.1908	67.69
154	0.17121	91.1898	0.19102	76.29
155	0.57394	61.3555	0.61517	52.67
156	0.13406	67.4911	0.15073	58.57
157	0.15	51.021	0.1697	43.8
158	0.11078	91.3439	0.12511	78.05
159	0.28318	82.5043	0.31178	71.54
160	0.21966	59.3009	0.23195	52.75
161	0.15915	75.9742	0.1695	66.96
162	0.19532	67.9508	0.20904	61.17
163	0.17957	67.9707	0.19385	62.38
164	0.17988	70.6422	0.19539	64.37
165	0.18329	72.9436	0.19908	66.79
166	0.1907	58.5628	0.20767	54.56
167	0.15435	49.9816	0.16962	47.68
168	0.13834	56.117	0.15475	54.59
169	0.16311	55.1616	0.18388	54.6
170	0.16359	54.8721	0.18575	54.73
171	0.16452	55.5309	0.18783	55.36

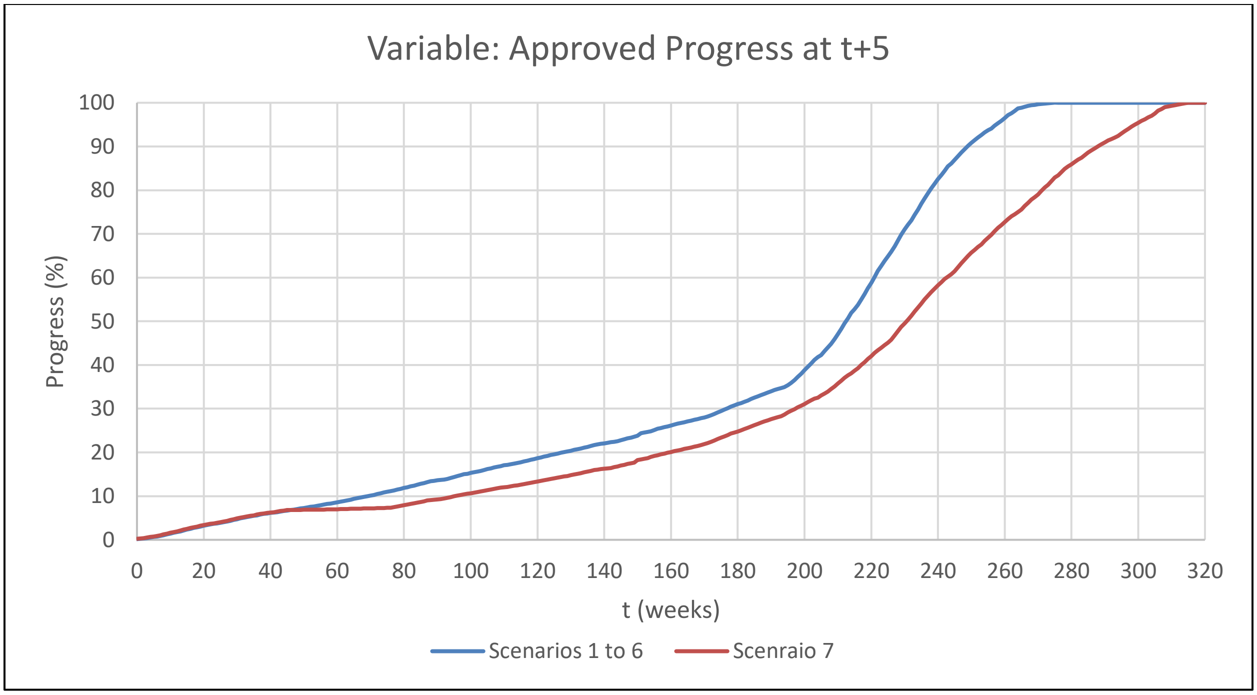
Time	Actual Weekly Progress % (Project)	Actual Weekly Staffing (Project)	Planned Weekly Progress % (Project)	Planned Weekly Staffing (Project)
172	0.16688	54.2374	0.19148	55.15
173	0.16602	55.601	0.19128	55.76
174	0.16661	57.6813	0.19325	59
175	0.1765	59.6211	0.20974	61.04
176	0.2205	60.2732	0.25864	61.26
177	0.27862	60.1807	0.31953	62.11
178	0.27954	61.7696	0.32156	63.93
179	0.28208	60.7114	0.32773	64.62
180	0.28005	60.2145	0.32684	66.11
181	0.28086	61.5394	0.32924	66.9
182	0.28178	61.9547	0.33055	67.33
183	0.28372	49.9909	0.33314	55.05
184	0.22376	48.1601	0.26802	55.36
185	0.1735	56.7376	0.23048	68.2
186	0.2027	57.7435	0.27941	76.03
187	0.20703	57.9451	0.31282	83.28
188	0.2093	54.1933	0.3359	62.23
189	0.1947	53.6561	0.30924	53
190	0.19494	54.7648	0.29065	45.16
191	0.21983	55.0852	0.28112	40.83
192	0.21948	54.7175	0.31367	41.79
193	0.21597	55.8158	0.30043	44.58
194	0.22705	62.222	0.28585	50.17
195	0.27611	60.4416	0.26512	58.32
196	0.24297	40.8509	0.28875	35.34
197	0.15779	42.235	0.17161	40.73
198	0.16683	65.5631	0.22649	66.05
199	0.25895	64.2112	0.41095	75.27
200	0.27541	63.3356	0.52632	80.58
201	0.27503	62.8212	0.65963	86.17
202	0.26972	66.9063	0.74759	92.12
203	0.32475	71.3391	0.75795	93.12
204	0.32358	70.1987	0.75637	100.96
205	0.28944	79.1496	0.73867	95.84
206	0.32711	86.6187	0.80299	99.97
207	0.36534	75.8882	0.81595	85.83
208	0.31118	56.4643	0.68726	55.24
209	0.21766	96.3697	0.45206	116.37
210	0.4206	76.4152	0.90069	120.74
211	0.37578	67.05	0.86224	111.63
212	0.32173	78.328	0.74949	140.29
213	0.38256	83.8738	1.09507	142.31
214	0.39112	74.2806	1.1479	145.49
215	0.37911	149.228	1.21901	151.09
216	0.53707	76.8832	1.27436	150.45
217	0.38704	82.5096	1.17	162.46
218	0.42094	57.3305	1.19242	107.14
219	0.28538	69.18	0.80769	136.57
220	0.33304	80.8483	1.06466	158.98
221	0.42252	80.8186	1.17366	173.36
222	0.41634	83.4661	1.31379	183.27
223	0.42561	77.1681	1.27811	194.04
224	0.35852	90.9723	1.29488	189.38
225	0.49779	84.8981	1.25661	203.96
226	0.41659	92.582	1.3993	197.11
227	0.46476	80.0139	1.18172	192.63
228	0.39064	82.1767	1.09422	183.84
229	0.42405	85.7943	1.08741	174.53
230	0.40932	88.7436	1.06473	179.69
231	0.40811	91.0169	1.22275	189.96

Time	Actual Weekly Progress % (Project)	Actual Weekly Staffing (Project)	Planned Weekly Progress % (Project)	Planned Weekly Staffing (Project)
232	0.40667	88.7818	1.31911	179.35
233	0.44077	82.5193	1.30838	174.78
234	0.40609	78.1999	1.2761	143.68
235	0.35907	85.2441	1.00634	147.89
236	0.38098	91.3525	1.03379	170.8
237	0.43868	84.1179	1.25741	163.88
238	0.44666	92.1982	1.2698	165.8
239	0.55166	102.526	1.26034	151.97
240	0.65666	80.6049	1.20159	149.89
241	0.4573	84.0005	1.22496	142.11
242	0.44766	85.5612	1.14557	128.49
243	0.47515	80.1562	1.07602	137.77
244	0.4618	79.2619	1.01923	129.14
245	0.40807	83.4821	0.95839	131.47
246	0.42702	83.1349	0.96237	134.08
247	0.41399	58.1367	0.97888	85.78
248	0.2956	71.9231	0.64647	102.65
249	0.45365	78.1136	0.83702	104.52
250	0.53558	77.9669	0.88199	103.48
251	0.547	80.4236	0.80659	119.63
252	0.56328	81.628	0.77965	118.23
253	0.58719	79.45	0.75684	111.89
254	0.56896	85.7336	0.69405	102.78
255	0.59133	76.4859	0.64111	93.46
256	0.54149	80.5237	0.59522	83.86
257	0.56148	80.3294	0.57612	78.21
258	0.56215	70.6897	0.5552	67.93
259	0.4629	52.7627	0.50392	50.31
260	0.36653	77.0559	0.42251	72.23
261	0.5458	77.8578	0.61861	67.46
262	0.51904	65.6991	0.6182	52.37
263	0.37956	84.7087	0.50954	61.03
264	0.48676	82.5673	0.63563	59.54
265	0.48853	84.699	0.62269	59.76
266	0.50519	82.6278	0.45074	59.6
267	0.49733	82.8302	0.55658	56.41
268	0.4942	67.3346	0.54269	55.64
269	0.40645	82.4048	0.19845	43.37
270	0.51619	82.4582	0.21327	41.17

Time	Actual Weekly Progress % (Project)	Actual Weekly Staffing (Project)	Planned Weekly Progress % (Project)	Planned Weekly Staffing (Project)
271	0.53099	80.6296	0.19049	34.32
272	0.50961	80.5426	0.14631	33.17
273	0.50543	82.4926	0.10164	23.72
274	0.49853	88.1556	0.10164	18.2
275	0.5251	86.4118	0.08477	16.14
276	0.52332	90.3912	0.07823	16.14
277	0.52798	90.8678	0.06685	13.24
278	0.53452	95.9113	0.06685	12.05
279	0.57625	90.5015	0.05856	0.44
280	0.548	86.9576	0.00198	0
281	0.53753	87.8076		
282	0.54047	86.5026		
283	0.53952	89.6632		
284	0.55057	89.8038		
285	0.54728	93.5132		
286	0.56155	90.9233		
287	0.55921	91.4167		
288	0.5793	80.2459		
289	0.51274	76.2219		
290	0.51149	103.849		
291	0.68233	97.5144		
292	0.61838	90.2264		
293	0.58609	94.6084		
294	0.65365	92.3368		
295	0.641	96.4439		
296	0.6758	97.3899		
297	0.68574	94.0172		
298	0.6672	50.0028		
299	0.34598	92.3982		
300	0.67041	76.5707		
301	0.55186	93.2595		
302	0.66431	102.515		
303	0.69108	122.969		
304	0.75644	111.239		
305	0.71116	128.732		
306	0.89829	64.9527		
307	0.492	0		

Variables that Depend on the Scenario





Max. Available Man Hrs
350
300
250
200
150
100
50
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320
t (weeks)
Planned & Scenario 1
Scenario 2
Scenarios 3, 8, 9, 10, 11
Scenarios 4 & 5
Scenarios 6 & 7

VITA

Ibrahim Abotaleb was born in Egypt in 1991. Abotaleb earned both his B.Sc. and M.Sc. degrees in Construction Engineering and Management from the American University in Cairo, Egypt; where he was awarded multiple honors and fellowships for his academic and extracurricular performance. Parallel to his masters, Abotaleb worked in ACE Project Management - one of the top consulting and project management firms in Egypt - for two and a half years as a commercial engineer. In the course of his work, Abotaleb actively participated in the planning, cost control, contract administration, and field supervision activities of construction projects worth over $600 million. Abotaleb also worked as a teaching assistant at the American University in Cairo (2012-2015) and at the University of Tennessee (2015-2018).

During his PhD program, Abotaleb was a holder of the prestigious Chancellor's Graduate Fellowship. Recently, Abotaleb was selected as an outstanding reviewer twice by the ASCE's Journal of Management in Engineering. To this date, Abotaleb has 10 peer-reviewed journal publications and gave 11 conference presentations as well as several invited talks.